Utilization of

Petroleum Engineering Technology

in the

Renewable Energy Sector

Master Thesis
Chair of Drilling Engineering

Montanuniversität Leoben

Aichinger Florian, B.Sc.

1st Supervisor: Univ.-Prof. Dr.mont. Gerhard Thonhauser
2nd Supervisor: DI Oliver Tausch

Written from May 2010 to June 2011

Eidesstattliche Erklärung

Ich erkläre an Eides statt, dass ich diese Arbeit selbstständig verfasst, andere als die angegebenen Quellen und Hilfsmittel nicht benutzt und mich auch sonst keiner unerlaubten Hilfsmittel bedient habe.

Affidavit

I declare in lieu of oath, that I wrote this thesis and performed the associated research myself, using only literature cited in this volume

Datum

Unterschrift

Abstract (German)

Angesichts der prophezeiten Verknappung fossiler Reserven und der damit verbundenen Energiekrise, wird Ausschau nach alternativen Energie Versorgungsmöglichkeiten gehalten.

Staatliche Förderung und erhöhte Aufmerksamkeit von Unternehmen in Forschung und Entwicklung haben in der Vergangenheit schon gute Ergebnisse erzielt. Auch wenn es angesichts des enormen derzeitigen Energieverbrauches von fossilen Brennstoffen nicht danach aussieht, als ob es mittel oder langfristig möglich wäre diese zu ersetzen.

Die besondere Aufmerksamkeit dieser Arbeit liegt auf dem Potential einer klassischen Öl und Gas Firma, unter der Ausnutzung ihrer Kernkompetenzen, am alternativen Energieversorgungssektor teilzuhaben. Dies wurde am Beispiel einer Firma untersucht, welche ihren technischen Hauptsitz in Gampern Oberösterreich, geologisch gesehen also im Molasse Becken hat.

Im Laufe der Arbeit werden vielfältige Möglichkeiten mit Hilfe eines Bewertungs - Programmes, auf der Basis von Excel und Visual Basic Applikationen, untersucht - von klassischen Geothermie Projekten in verschiedenen Varianten, bis hin zur Wärme und Stromspeicher Nutzung.

Aufgrund dieser wirtschaftlichen und technischen Überlegungen wurde kurz und mittelfristig die unterirdische Wärmespeicherung, als Markt mit dem größten Potential angesehen. Um dies zu untermauern wurde für eine Forschungs und Entwicklungs Firma in Leoben eine Voruntersuchung zu dem Pilotprojekt „Wärmespeicher - Biogasanlage Josef Schwarzmayr“ in St Georgen bei Obernberg am Inn durchgeführt.

Generell bezieht sich diese Arbeit auf die Geologie des Molassebeckens und dementsprechend bezüglich der wirtschaftlichen Situation auf Deutschland und Österreich, in dessen Staatsgebieten sich ein großer Teil des Beckens erstreckt.

Abstract (English)

Facing predicted uprising shortage of fossil energy reserves and energy crisis going along with it, efforts are taken to develop and implement renewable energy supply.

Federal support and private contribution in research and development have yielded good results in the past. However comparing absolute numbers of the enormous fossil energy demand and (until now) relatively little contribution of renewables, it seems hard to believe, that we will be able to substitute them on mid or long term sight.

The focus of this work is on the possibilities for a classic oil and gas company to contribute to the renewable market. This was exemplary investigated at a company, which has its technical main quarter in Gampern, Upper Austria –therefore geologically seen in the Molasse Basin.

From classic geothermal wells to heat and electric energy storage various project types were investigated with the help of an evaluation spread sheet

Due to economic and technical considerations the heat storage market was identified to have the highest potential, on the short and medium term. To back up this statement, a pre investigation of the pilot project “Heat storage – Biogas facility Schwarzmayr” in St. Georgen bei Obernberg am Inn was performed, for a research and development company in Leoben.

In general this work reveres geologically to the Molasse basin and accordingly to the political situation in Germany and Austria , which national territories cover most of the basin.

Foreword of the author

Originally this Master thesis was offered by the Drilling Department, meant to investigate possible drilling problems of deep geothermal wells in the Molasse basin. More specific: Wells which are capable of producing electricity applying Kalina or ORC (Organic Rankine Cycle) power plant technology. Under average given geologic circumstances in the area, this would mean deeper than 3500 m TVD (Total Vertical Depth) having a final casing diameter of at least 7 [in] (to achieve suitable production).

With the application of especially the software "Well Cat" and other tools of the "Landmark package", variable simulation runs should have been performed, focusing on effects of variables like –*Temperature gradient; TDV; End casing diameter; Well path; Corrosion; Usage as injector or producer well, etc.* – on the necessary design and furthermore on the total well costs. In other words a sensitivity analysis on cost drivers of large diameter HTHP wells (High Temperature High Pressure). Additionally cost saving potential of state of the art technology should have been investigated.

To fulfil the requirements for being accepted as a master thesis in the Drilling Department of University Leoben, it was agreed that the economics of the total project (Electricity output vs. temperature (i.e. TVD) <-> Optimal depth; Electricity requirement for the pumps; Role of remaining energy usage in a heat distribution network, etc.) should be also part of this thesis.

On the 3rd of May (2010) the work on the thesis started in Gampern supervised by Univ. Prof. Dr. Thonhauser and DI Tausch.

After learning the basics of the Landmark software package and carrying out a literature/internet research on those kinds of drilling projects, two things became clear very soon. First, there is a complete lack of published drilling data concerning these wells in the area and secondly the few published progress reports mentioned various different drilling problems. Therefore I doubted that simulation runs without reliable data and even unknown scenarios would have yield usable results.

The scope of the work was swift to the economics of the overall project, trying to find optimal depth and investigating location requirements. As neither the economics nor the energy efficiency of these projects yielded satisfying results, other possibilities for using drilling technology in the renewable energy sector were searched for. Starting with geothermal heat supply in different sizes and application types, usage as heat storage in combination with various other (renewable) energy sources, supporting of existing heat distribution and electricity producing systems, and finally electrical energy storage was investigated.

To do this properly and being able to evaluate the importance of various input parameters an evaluation spread sheet was written, parts of it will also be presented in the following.

The description and evaluation of the different project types, was presented to technicians of RAG in August 2010. Most important result was, that the development of heat storage systems, have probably a higher potential, than the originally anticipated large scale Geothermal projects.

In the following month September to December (2010), ideas concerning heat storage systems were developed further, without being employed. On the 14th of January I started my work at a research and development company in Leoben, a summary of the results were given to the company management, and it was agreed to follow up.

From January to May (2011) a pre investigation of the pilot project “Thermal storage – Biogas facility Schwarzmayr” was done.

Working on this thesis was interesting for me, I learned that the alternative energy sector has a wide range of application types, and most of them are on the economic borderline (or on the negative side). But there are examples, where good individual planning and engineering developed various different ways that allowed a beneficial application of alternative energy support.

Acknowledgments

I want to thank **DI Süß** and **DI Tausch** from **RAG** for allowing me to work completely free, being patient and very supportive, even when I was asking for changing the focus (and date of hand in) of the work multiple times. **Prof. Thonhauser**, who during times working for RAG helped me not to get lost in details, bringing the work back on a promising trail, again and again. Most however of course for offering the chance to follow up some ideas in his company **ADS TDE**.

Further **DI Rabengruber** who allowed me insight in his work helping me a lot developing the economic part of my evaluation software. **DI Mayer** who supported me with information and literature concerning thermodynamic details in power plant processes. **Mr. Schwarzmayr,** who patiently explained me the tasks of container corn drying; **DI Schweiger** for personal information on jet grouting technique; **Hon. – Prof. Dipl. – Ing. Dr. mont Schmid** for his help gaining relevant geological information, and last but not least **Ing. Kirchmeyr** for helping me a lot identifying a fitting location for a pilot project pre study, and further for representing the project towards the “OeMAG”

Table of contents

Abstract (German) 5

Abstract (English) 7

Foreword of the author 9

Table of contents 13

Table of figures 21

SECTION 1

1 Target..31

2 Project decision matrix 32

3 Introduction 33

3.1 Introduction – Possible applicable oil and gas technology in the renewable energy sector 33

3.2 Introduction - Market situation: Renewable energies 33

3.2.1 Introduction – Market situation: Renewable electric energy 33

3.2.2 Introduction – Market situation: Renewable heat energy.............................. 35

3.2.3 Introduction - Project Types 35

4 Evaluation and predesign of an energy concept – Overview 36

5 Evaluation software- Overview 37

5.1 Evaluation software - Brief description of main modules 38

5.1.1 Overview 38

5.1.2 Demand 38

5.1.3 Energy concept 38

5.1.4 Economics 39

6 Evaluation and predesign of an energy concept – Strategic preliminary decisions 40

6.1 Selection of fitting location and time 40

6.2 Requesting interest from main potential customers 40

6.3 Pricing and financing 40

6.3.1 Customers connection behaviour 41

6.4 Heat energy prices 43

6.5 Evaluation software - Heat energy prices 43

6.6 Marketing and information in concerned community 45
6.7 Heat energy demand analysis and prognosis 46
6.7.1 Types of heat energy demand 46
6.7.2 Gaining information about required heat energy 46
6.7.3 Distribution of domestic water demand over a year 48
6.7.4 Distribution of total energy demand over a year 48

7 Distribution of energy (and power) demand concerning geographic situation and network 50
7.1 Main distribution 50
7.2 Sub distribution and adaption of buildings 51
7.3 Dimensioning – Optimization of network 52
7.3.1 Pipe diameter 52
7.3.2 Forward and backward flow temperature 52
7.3.3 Pumping costs 53
7.3.4 Operation type 54
7.3.5 Limitations of “Temperature controlled” regulation 55
7.3.6 Necessary temperature levels for utilizing heating energy 55
7.3.7 Temperature levels for home heating stations 56
7.3.8 Simultaneity factors 59
7.3.9 Type of home stations 61
7.4 Pipe line construction costs 65

8 Evaluation software - Demand 66
8.1 Evaluation software - Total demand 66
8.1.1 Heating energy demand input for rough estimations 66
8.1.2 Heating energy demand input required for predesign 67
8.2 Evaluation software – Construction of demand line 69
8.2.1 Heating and domestic water energy 69
8.3 Evaluation software - Network 72
8.3.1 Approximation of network costs 74

9 Evaluation software –Dynamic demand line 81
9.1 Evaluation of software –Constructing dynamic demand line 82
9.1.1 Rough estimation mode 82
9.1.2 Pre design mode 83

10 Energy concept 84
10.1 Predesign of energy suppliers 84
10.1.1 Utilization of partial adjustment range 84
10.1.2 Criteria for base and peak load suppliers 85

11 Evaluation software - Energy concept 87
11.1 Input sheet... 87
11.2 Operation type.. 88
11.2.1 Strict heating demand operation 88
11.2.2 Heating demand operation 89
11.2.3 Power demand operation (including seasonal storage) 90
11.2.4 Strict power demand operation 90
11.2.5 Strict power demand operation including seasonal storage 90
11.2.6 Operated as storage 91
11.2.7 Operated as peak load... 95
11.2.8 Operated as support... 96
11.2.9 Summary energy concept... 96

12 Predesign of energy suppliers 97

13 Geothermal wells 98
13.1 Definition of subject matter 98
13.2 Geothermal Energy in general... 98
13.2.1 Geothermal energy origination 98
13.2.2 Usage of geothermal energy 99
13.2.3 Geological description of the Molasse basin.................................. 99
13.2.4 Is geothermal energy renewable?... 101
13.3 Utilization of geothermal energy for large scale projects 103
13.3.1 Set up 103
13.4 Drilling technology... 105
13.4.1 Drilling recommendations for a typical geothermal well in the area 105
13.5 Material and instrumentation problems due to temperature....................... 109
13.5.1 Change of mud properties – Loss of circulation........................... 109
13.5.2 Thermal effects on casing... 111
13.5.3 Effects on instrumentation... 112
13.5.4 Directional drilling 113
13.5.5 Logging tools... 113
13.5.6 Effects on seals 114
13.6 Drilling technologies with cost saving potential............................ 114
13.6.1 Expandable tubular casing.. 114
13.6.2 Under reamers.. 114
13.6.3 Low clearance casing design... 115
13.6.4 Drilling with casing.. 115
13.6.5 Multilateral completions /stimulating through side tracks and laterals........ 115
13.6.6 Well design variations... 115

13.7 Geothermal electric power plant technology 116
13.7.1 Clausius Rankine Cycle 116
13.7.2 Clausius Rankine Cycle efficiency and furnace bulk temperature 117
13.7.3 Possible improvements of the Clausius Rankine process 118
13.8 Geothermal energy usage in classic fossil power plants 122
13.9 Low temperature power plants 122
13.9.1 Organic Rankine Cycle (ORC) power plants 122
13.9.2 Kalina cycle power plants 124
13.9.3 Comparison of both power plant types 125
13.9.4 Investment costs of discussed low temperature power plant types 128

14 Evaluation software – Geothermal wells 129

14.1 Basic settings in module “Overview” 129
14.2 Program module “Production” 130
14.2.1 Electricity production 130
14.2.2 Wellbore pre design 132
14.2.3 Choose fitting casing design 135
14.2.4 Temperature levels and necessary power plant bypass 136
14.3 Program module “Well bore cost approximation” 137

15 Large scale projects including geothermal wells 139

15.1 Large scale geothermal heating energy supply 139
15.1.1 Comment 139
15.1.2 Project set up 139
15.1.3 Theoretical creation of value 140
15.1.4 Example large scale project geothermal heating supply 142
15.1.5 Conclusion – large scale geothermal heating supply projects 145
15.2 Geothermal electric power and heating energy production 146
15.2.1 Comment 146
15.2.2 Project set up 146
15.2.3 Most important influences on economics 147
15.2.4 Example: Geothermal electric power and heating energy production 148
15.2.5 Conclusion –electric power and heating energy production 153
15.3 Support of fossil power plants with geothermal energy 155
15.3.1 Comment 155
15.3.2 Conclusion – Support of fossil power plant with geothermal energy 161

16 Geothermal heat storage 162

16.1 Applications 162
16.2 Sediments ability to store heat 162
16.3 Principal underground storage types 164

16.3.1 Aquifer storage systems 164
16.3.2 Borehole thermal energy storage (BTES) 166

16.4 Thermal storage systems in combination with solar energy 167
16.4.1 Solar district heating with seasonal aquifer storage system - Rostock 168
16.4.2 Solar district heating with BTES seasonal storage system - Attenkirchen 171
16.4.3 Conclusion – Solar storage systems 173

16.5 Thermal storage systems in combination with heat and power producing units (CHP) 174

16.6 Thermal storage systems combined with biogas CHPs 174
16.6.1 Biogas CHPs 174

16.7 Evaluation software – Biogas CHP units 183
16.7.1 Pre design of CHP unit 183
16.7.2 Federal support 184
16.7.3 Pre design of fermenter unit 184
16.7.4 Investment cost calculation 186

16.8 Projects description: Heat energy storage combined with Biogas CHP 187
16.8.1 Comment 187
16.8.2 Assumptions 187
16.8.3 Project set up 188
16.8.4 Theoretical creation of value 188
16.8.5 Increase of economics due to straightening of static demand line 189
16.8.6 Increase of economic due to straightening of dynamic demand line 194
16.8.7 Conclusion – large scale geothermal heating supply projects 196

16.9 CHP biogas units combined with geothermal storage including gas preparation 196
16.9.1 Project set up 197
16.9.2 Anticipated advantages 197
16.9.3 Drawbacks 199
16.9.4 Conclusion – Biogas preparation 199

16.10 Comparison of biogas CHPU project assumptions to reality 199
16.10.1 Conclusion biogas CHPs and geothermal storage 201

16.11 Heat energy Storage combined with other CHPs 201
16.11.1 Potential 202

16.12 Project description: Heat energy storage combined with other CHP 203
16.12.1 Comment 203
16.12.2 Project set up 203
16.12.3 Assumptions 204
16.12.4 Evaluation 205
16.12.5 Conclusion 207
16.12.6 Conclusion thermal storage systems – from Drillers point of view 207

17 Electricity storage 208
17.1 General 208
17.2 Basic concept 208
17.3 Technical problems 208
17.4 Set up 209
17.5 Facilities and efficiencies 209
17.6 Economics 209

18 Final conclusion and recommendations 212
18.1 General 212
18.2 Actual situation from the author’s point of view 212
18.2.1 Geothermal electric energy 212
18.2.2 Geothermal heat supply 213
18.3 Most promising projects from the author’s point of view 214
18.3.1 Heat storage 214
18.3.2 Electric energy storage 215
18.4 Fulfilment of set targets 215
18.5 General situation of the renewable energy market from the author’s point of view 216

SECTION 2

19 Target 221

20 Pilot project: Biogas CHPU “Schwarzmayr” 222
20.1 Project overview 222
20.2 Waste energy uesage 222
20.3 Waste Energy utilization economics 223
20.3.1 Comments to the most important heating energy demanders 224
20.3.2 Qualification for “KWK Bonus” 225
20.4 Anticipated economical improvements utilizing a thermal storage 225
20.4.1 Desired effects and energy amount 225
20.4.2 Desired Effects – Economic Value 226
20.5 Technical feasibility – Facility 227
20.5.1 Drying process – Facility set up 227
20.5.2 Container drying process – Required energy – Thermodynamic principle 228
20.5.3 Container drying process – Bringing (additional) energy to the system 233
20.5.4 Container drying process – Corn properties and corn drying 235

20.5.5 Container drying process – Expected results of increasing drying air stream ... 236
20.5.6 Container drying process - Conclusion ... 237
20.6 Ideal storage layout – Size and power ... 238
20.6.1 Required temperatures / Required power ... 238
20.7 Technical feasibility – Geology / Storage ... 241
20.7.1 Geological overview ... 241
20.7.2 Shallow geology ... 241
20.7.3 Intermediate geology ... 243
20.7.4 Deeper geology ... 246
20.8 Technical feasibility - Storage ... 246
20.8.1 Aquifer storage “Treubacher Sande” sequence ... 246
20.8.2 Hybrid storage “Gravel” layer ... 248
20.9 Conclusion thermal storage project “Schwarzmayr” ... 252
20.10 Future visions – Embedded intelligent thermal storage system ... 253

21 Final conclusion from the drilling engineer’s point of view ... 255

22 Bibliography ... 259

Table of figures

Figure 1: *Project decision matrix* 32

Figure 2: *Federal electric energy support [1]* 34

Figure 3: *Evaluation software basic description [own illustration]* 37

Figure 4: *Scenario settings and results* 41

Figure 5: *Graphic illustration of customer connection behaviour [own illustration]* 41

Figure 6: *Graphic illustration of resulting cumulative revenues [own illustration]* 42

Figure 7: *Heat energy price evaluation spread sheet – calculates yearly costs for different heating systems [own illustration]* 44

Figure 8: *Communication advisor – Information activities during project lifetime [own illustration modified according to [3]* 46

Figure 9: *Dependence of heating energy demand form outside Temperature [4]* 47

Figure 10: *Heat demand depending on outside temperature [5]* 47

Figure 11: *Distribution of total energy demand over a year (Demand line) [4]* 48

Figure 12: *Energy demand distribution for selected buildings. (Demand line) [Modified according to 4]* 49

Figure 13: *Daily peak in domestic water demand [4]* 49

Figure 14: *Illustration of different main distribution network types [4]* 50

Figure 15: *Sub distribution: Standard* 51

Figure 16: *Sub distribution: House to house* 51

Figure 17: *Sub distribution: Flexible pipes ("Einschleifmethode") [4]* 51

Figure 18: *Required Pump performance vs. volumetric flow [own illustration]* 54

Figure 19*:* *Temperature controlled operation type [modified according to 6]* 55

Figure 20: *Lindsay diagram – Required temperature level for different applications [unknown source – website inactive]* 57

Figure 21: *Growth curve for some crops [unknown source– website inactive]* 58

Figure 22*:* *Growth curve for some food animals [unknown source– website inactive]* 58

Figure 23: *Simultaneity factor function tested in a reference networks [5]* 60

Figure 24: *Simultaneity factor for domestic water (storage system) [4]* 61

Figure 25: *Flow through system [4]* 62

Figure 26: *Storage System [4]* 63

Figure 27: *Flow through storage system* 63

Figure 28: *Pipe line cost distribution [own illustration information according to 4]* 65

Figure 29: *Build-up of main program "Demand". [Own illustration]* 66

Figure 30: *Estimation of total demand, based on average values for building types [own illustration]* 66

Figure 31: *Specific data input for single buildings [own illustration]* 67

Figure 32: *Specific data for buildings of the same type [own illustration]* 68

Figure 33: *Definition of reference numbers chosen in Open Jump [own illustration]* .. 68

Figure 34: *Input sheet: Climate data [own illustration]* 69
Figure 35: *Sorted temperature distribution [own illustration]* 70
Figure 36: *Additional Input concerning climate data and heating energy [own illustration]* 70
Figure 37: *Heating demand – characteristic numbers (line) [own illustration]* 71
Figure 38: *Demand Line [own illustration]* 71
Figure 39: *Creating network in Open Jump [own illustration]* 72
Figure 40: *Connection areas of pipes [own illustration]* 73
Figure 41: *Calculation of Vmax and rules of numeration [own illustration]* 74
Figure 42: *Rules for summarized branch numeration [own illustration]* 75
Figure 43: *Transferrable energy for various pipe diameters [according to 7]* 76
Figure 44: *Definition of net branches identification numbers [own illustration]* 77
Figure 45: *Material and construction costs for various diameters (plastic coated pipes) [own illustration according to 7]* 78
Figure 46: *Network evaluation spread sheet [own illustration]* 79
Figure 47: *Cumulated costs of network [own illustration]* 80
Figure 48: *Development of demand [own illustration]* 81
Figure 49: *Input spread sheet – rough estimation dynamic demand line [own illustration]* 82
Figure 50: *Visualisation of dynamic demand line [own illustration]* 82
Figure 51: *Influence of stages of construction on dynamic demand line [own illustration]* 83
Figure 52: *Dynamic demand line during project life [own illustration]* 83
Figure 53: *Load types on demand line [modified 4]* 84
Figure 54: *Module wise base load distribution [modified 4]* 85
Figure 55: *Input of energy concept parameters [own illustration]* 87
Figure 56: *Strict heating demand operation [own illustration]* 88
Figure 57 *Heating demand operation [own illustration]* 89
Figure 58: *Power demand operation including seasonal storage [own illustration]* 90
Figure 59: *Basic settings for seasonal storage [own illustration]* 91
Figure 60: *Storage input vs. output [own illustration]* 91
Figure 61: *Efficiency development of a storage system (Assumed values) [own illustration]* 92
Figure 62: *Optimum nominal base load for a seasonal storage [own illustration]* 92
Figure 63: *Input Cells “Predesign of storage”[own illustration]* 94
Figure 64: *Optimized nominal base load and chosen approach [own illustration]* 94
Figure 65: *Adjustment of storage in and output by days online [own illustration]* 95
Figure 66: *Operation as peak load [own illustration]* 95
Figure 67: *Geological profile between Freising and Miesbach (Bavaria) [8]* 99
Figure 68: *Summary - Hydrothermal potential Bavaria [according to 8]* 100
Figure 69: *Production rate and dynamic level range in the Molasse basin [according to 8]* 101

Figure 70: *Illustration of geothermal system and reservoir [unknown source]* 102
Figure 71: *Typical set up of an electric power producing geothermal project in Molasse basin [own illustration]* 104
Figure 72: *Vertical section of a possible production well design [9]* 105
Figure 73: *Illustration of two technologies to lighten up the mud weight with air [9]* 110
Figure 74: *Yield strength of casing steel qualities as a function of Temperature [unknown source]* 111
Figure 75: *Clausius Rankine Cycle (CRC) [modified 11]* 116
Figure 76: *Illustration of furnace bulk temperature [own illustration]* 117
Figure 77: *Furnace bulk temperature in the CRC (T – S diagram) [modified 11]* 118
Figure 78: *Effect of increasing T2 (boiler temperature) on efficiency [11]* 118
Figure 79: *Effect of increased pressure on Tm [modified 11]* 119
Figure 80: *Schematic of a CRC including reheating [modified 11]* 119
Figure 81: *CRC including reheating in a T – S diagram [modified 11]* 120
Figure 82: *Schematic of CRC including feed water preheating [modified 11]* 120
Figure 83: *CRC including preheating T – S diagram [modified 11]* 121
Figure 84: *Schema of a simple Organic Rankine Cycle process [12]* 122
Figure 85: *T – S diagram of a typical ORC process [13]* 123
Figure 86: *Classic improvements imbued on an ORC process [13]* 123
Figure 87: *Schema of a Kalina cycle process [12]* 124
Figure 88: *Power plants backflow temperatures [13]* 125
Figure 89: *Thermal efficiency of ORC and Kalina power plants [13]* 126
Figure 90: *ORC power plants electricity requirements [13]* 126
Figure 91: *ORC power plants electricity requirements [13]* 127
Figure 92: *Net efficiency of ORC and Kalina power plants [13]* 127
Figure 93: *Specific Investment costs geothermal power plants [13]* 128
Figure 94: *Basic Project settings in “Overview” [own illustration]* 129
Figure 95: *Additional settings for electricity production in “Production” [own illustration]* 130
Figure 96: *Predesign settings of wellbore [own illustration]* 132
Figure 97: *Viscosity of water depending of temperature and pressure [own illustration]* 133
Figure 98: *Illustration of well path [own illustration]* 134
Figure 99: *Schema of casing shoes measured depth [own illustration]* 134
Figure 100: *Casing design [own illustration]* 135
Figure 101: *Casing design schemas [own illustration]* 136
Figure 102 *Temperature bottleneck [own illustration]* 136
Figure 103: *Compare able bore holes (RAG data cleared in public version) [own illustration]* 137
Figure 104: *Cost distribution of one producing well [own illustration]* 138

Figure 105: Range of oil and gas bore hole costs in the Molasse basin [own illustration, based on RAG data] (RAG data cleared in this version) 138

Figure 106: *Project set up of a large scale geothermal heating energy supply [own illustration]* 139

Figure 107: *Theoretical creation of value per MWh [own illustration]* 140

Figure 108: *Most important influences on economics – Geothermal projects [own illustration]* 140

Figure 109: *Examples demand line [own illustration]* 142

Figure 110: *Examples costumer behaviour [own illustration]* 142

Figure 111: *Example project revenues [own illustration]* 143

Figure 112: *Example project: Sensitivity analysis – Project value [own illustration]* 143

Figure 113: *Energy flux diagram [own illustration]* 144

Figure 114: *Cost distribution of geothermal well for heating energy support [own illustration]* 144

Figure 115: *Project set up: Geothermal electric power and heating energy production [own illustration]* 146

Figure 116: *Theoretical creation of value per produced MWh used as heating energy [own illustration]* 146

Figure 117: *Theoretical creation of value per produced MWh used in power plant [own illustration]* 147

Figure 118: *Examples demand line [own illustration*] 149

Figure 119: *Examples customer behaviour [own illustration]* 149

Figure 120: *Project revenues [own illustration]* 150

Figure 121: *Energy flux diagram [own illustration]* 151

Figure 122: *Energy efficiency of example project [own illustration]* 152

Figure 123: *Investment cost distribution [own illustration]* 152

Figure 124: Schema of the steam power plant block 4 “Staudinger” [14] 155

Figure 125: *Simplified schema of the Staudinger fossil power plant [own illustration according to 14]* 156

Figure 126: *Saving potential for different temperature levels per turbine [own illustration]* 158

Figure 127: *Saving potential for different temperature levels [own illustration]* 158

Figure 128: *Temperature levels at heat exchanger (for geothermal source 1) [own illustration]* 159

Figure 129: *Thermal Power of bypassed steam (grey) and geothermal energy substitute (brown) [own illustration]* 160

Figure 130: *Results geothermal source 1 [own illustration]* 160

Figure 131: *Results geothermal source 2 [own illustration]* 160

Figure 132: *Results geothermal source 3 [own illustration]* 160

Figure 133: Fossil power plant support potential in Germany [own illustration] 161

Figure 134 *Volumetric Heat Capacity of various rock types. (Range is mainly due to water content) [modified 18]* 162

Figure 135: *Schema of an aquifer storage* 164

Figure 136 *Typical ATES setup in the Netherlands for low temperature application (Heat pump supported) [16]* 165
Figure 137 *Sketch of a borehole and heat exchanger component of a storage system* 166
Figure 138 *Heat Energy demand and solar irradiation.* 167
Figure 139 *Rostock Brinckmannshöhe [19]* 168
Figure 140 *Hydraulic Scheme [modified 19]* 168
Figure 141 *Temperature development during discharging [own illustration according to 19]* 169
Figure 142 *Energy flux diagram [19]* 170
Figure 143 *Investment Costs of total project [according to 19]* 170
Figure 144 *"Overview District heating system Attenkirchen" [21]* 171
Figure 145 ***"****Hybrid Storage System utilized in Attenkirchen" [21]* 172
Figure 146 **"**Energy Flow Diagram Attenkirchen" [21] 172
Figure 147 *Investment costs Attenkirchen [21]* 173
Figure 148 *CHP Unit technical variations* 174
Figure 149*: Major components of a biogas CHP station [modified 2]* 175
Figure 150: *Gas production depending on dwell time [own illustration]* 175
Figure 151: *Electric efficiency vs. electric net power [15]* 178
Figure 152 *Investment costs vs. electric net power (referred to maximal fitting biogas CHPU size η=40%* 182
Figure 153: *Investment costs vs. electric net power [15]* 182
Figure 154 *Basic CHP unit settings [own illustration]* 183
Figure 155 *Predesign of fermenter unit 1 [own illustration]* 184
Figure 156 *Displayed fermentation behaviour curve* 185
Figure 157: *Project set up of a biogas CHP including a geothermal storage [own illustration]* 188
Figure 158: *Theoretical creation of value - Biomass CHP [own illustration]* 188
Figure 159: *Case 1 - No storage included – Demand line and heat energy support [own illustration]* 190
Figure 160: *Case 2 - $\dot{\eta}$= 90 % storage included – Demand line and heat energy support [own illustration]* 191
Figure 161: *Case 3 - $\dot{\eta}$= 75% storage included – Demand line and heat energy support [own illustration]* 191
Figure 162: *Comparison of power ratings and online time [own illustration]* 192
Figure 163*: Comparison of project economics [own illustration]* 192
Figure 164: *Influence of storage efficiency on revenues [own illustration]* 193
Figure 165: *Typical storage efficiency and demand development [own illustration]* ... 194
Figure 166: *Straightening of the dynamic demand line [own illustration]* 195
Figure 167: *Project set up -CHP units including geothermal storage and gas net* 197
Figure 168: *Fermenter facility investment and operation cost function* 197

Figure 169: *CHP unit investment and operation costs NG = Natural gas; BG = Biogas* 198
Figure 170: *federal biogas electricity support UoH: Utilizing of Heating Energy* 198
Figure 171 *Heat energy utilisation of 61 compared Biogas facilities in Bavaria [23]* .. 200
Figure 172 *Online hours per year of 61 compared Biogas facilities in Bavaria [23]* 200
Figure 173 *Technical Comparisons of CHP Units* 201
Figure 174 *Illustration of Austrian biomass (wood) heating power plants (green) and biomass CHP Units (red) 2007 [19]* 202
Figure 175 *Illustration of Austrian biomass (wood) heating power plants (green) and biomass CHP Units (red) 2010 [19]* 202
Figure 176 *Basic idea of a thermal storage utilized in a CHP project.* 203
Figure 177 *Assumed demand line and straightened demand line* 204
Figure 178 *Typical part load behaviour of an ORC process.* 205
Figure 179 *Investable Capital for the four discussed cases* 205
Figure 180 *Revenue origination and Revenue [€/y] differences for the four discussed projects.* 206
Figure 181 *Storage costs per Water Equivalent for various storage types and allowable storage costs per water equivalent for the assumed case.* 207
Figure 182: *Set up of a first generation CAES power plant. [24]* 209
Figure 183 *Optimal electricity storage size [25]* 210
Figure 184: *Comparison of PSPP and CAE storage system [data from 24]* 210
Figure 185 *Illustrated is a scheme of the existing facility [own illustration]* 222
Figure 186 *Heat Energy Utilization in percentage of total waste heat. [Own illustration]* 222
Figure 187 *Total Heating Energy Utilization in per cent [own illustration]* 223
Figure 188 *Drying facilities output in [t/d] (of dried bulk) Corn 6 – 8 weeks in September – November; Crop 0 – 1 week in July – August [own illustration]* 223
Figure 189 *Daily and typical yearly profit (50 days of corn drying season and 7 days wheat drying season assumed) [own illustration]* 223
Figure 190 *Sketch of the container drying facility [own illustration]* 227
Figure 191 *Base for calculating required heating energy/power [own illustration]* ... 228
Figure 192 *Table of water properties used for calculation spread sheet [own illustration - according to data of 35]* 228
Figure 193 *Water capacity of air as a function of Temperature [own illustration - according to data of 35]* 229
Figure 194 *Water capacity of air as a function of Temperature* 231
Figure 195 *Drying Energy demand Corn.* 232
Figure 196 *Drying Energy demand Woodchips.* 232
Figure 197 *Bringing (additional) energy to the system* 233
Figure 198 *Calculated Temperature levels during corn drying.* 234
Figure 199 *Microscopic image of one corn [28]* 235

Figure 200 *Drying speed for air drying at constant air stream, drying stages and approximate wetness ranges. [Modified 28]* 235

Figure 201 *Corn drying process within a container drying facility [own illustration]* .. 236

Figure 202 *Climate data weather station “Reichersberg” and illustrations according to thoughts about required storage temperature [own illustration]* 238

Figure 203 *Corn drying at average local Temperature in September (= 13 °C), requires a storage Temperature of 49 °C for double capacity [own illustration* 239

Figure 204 *Corn drying at average local Temperature in November (= 2, 5 °C), requires a storage Temperature of 42 °C for double capacity [own illustration]* 239

Figure 205 *Woodchips drying at average local Temperature in December (=-1°C), resulting in an possible capacity increase of 20 % [own illustration]* 240

Figure 206 *Geological Map of the area [modified 30]* 241

Figure 207 *Surface near geology as described by local well diggers and confirmed by Mr Schwarzmayr [own illustration]* 241

Figure 208 *Sediment cores from the test well in St. Georgen bei Obernberg am Inn (~1km distance). [Own photography]* 242

Figure 209 *Assumed equipotential pressure lines in gravel section (Constructed according to surface height differences) [modified 30]* 242

Figure 210 *Intermediate Geology, discussed according the 2, 5 km distanced geothermal well “Geinberg 2”. [Modified 31]* 243

Figure 211 *Mineralisation of underground water in the Molasse basin [31]* 245

Figure 212 *Geological cross section - passing by the facility [unknown source]* 246

Figure 213 *Sketch of a hybrid storage system constructed in the gravel layer [own illustration]* 248

Figure 214 *Picture of a jet grouted body [33]* 249

Figure 215 *Sketch of constructing a jet grouted body with an internal loop well in one step* 249

Figure 216 *Embedded intelligent thermal storage system [own illustration]* 253

Figure 217 *Electricity stock exchange prices – Year 2002 – 2006; the lines referring to different years, 2006 reflected by the lightest to 2002 reflected by darkest line* 253

Figure 218 *Shallow well drilling costs “Molasse Basin” [own illustration]* 255

Section 1

Theoretical Investigation of possible Project Types

Supported by:

RAG.AUSTRIA.ENERGIE

1 Target

The target of this work is to identify project types, which combine classic oil and gas with renewable energy technology. Further the projects shall have an economic and technical potential, which allows them being a real concurrence to oil and gas projects. Nowadays, alternative large scale energy projects, which for example include geothermal energy, are done as alibi projects, serving a community or companies to show they take care about ecology. Even though the project would never have made it to realisation, if it would have be judged as others. Or economical and technical risks are shifted from the company to community and state, by financing and federal support.

Target of this work therefor is, to identify projects utilizing Petroleum Engineering Technology within the Renewable Energy Sector, which offer good economics, however not as an exotic application but broad applicable.

In other words economics should be interesting, without assuming unrealistic or very seldom scenarios or circumstances. Of course a project is interesting if for example an oil well produces (with high water cut), free energy, which can be used by a greenhouse and a public bath nearby. However the requirements on the location, (already drilled and producing oil well and large low temperature energy demand nearby) are quite high, therefore this project type wouldn’t make it in the first choice.

On the other hand, it is possible to drill geothermal wells that transmit their energy to water cycled within the bore hole, nearly everywhere. The gained energy can be utilized by a heat pump, which grades up the energy to a temperature level usable in a wide range. Unfortunately these kinds of projects have high investment costs, considerable operation costs and commonly only very low internal rates of return are achieve able. (In a realistic customer scenario) therefor it would not be first choice either. In addition this sector is already completely occupied by specialised companies.

Summarized: Target shall be the identification of a project type that can be accomplished with Oil and Gas Technology which has a high potential and sufficient economic, in the renewable energy sector.

2 Project decision matrix

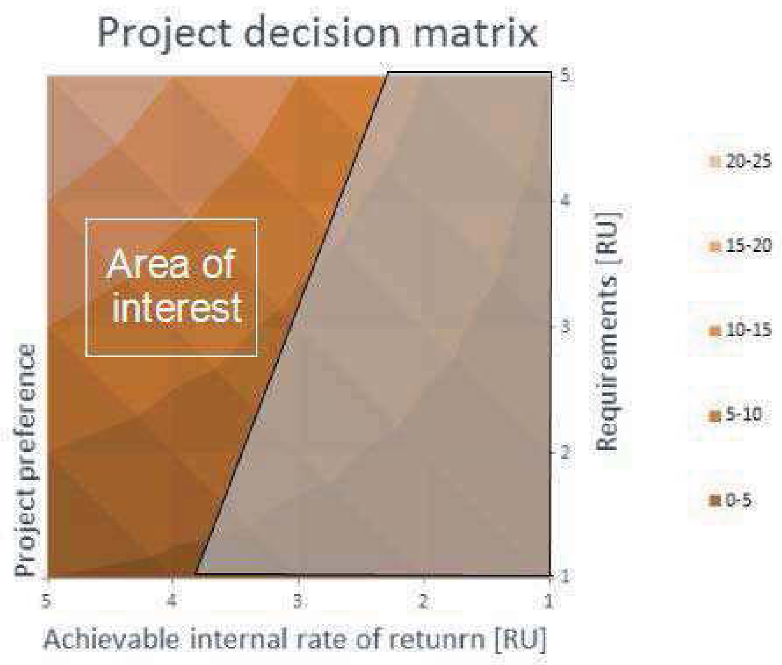


Figure 1: *Project decision matrix*

Both criteria (Achievable internal rate of return and project requirements) are rated in reference units from 1 to 5 (5 = best rating -> high internal rate of return and accordingly low requirements). The coloured area of the diagram originates from simply multiplying the ratings, yielding 25 for the best project and 1 for the worst.

As illustrated in Figure 1 the area of preference is asymmetric. If a project offers just average internal rate of return ratings but has good (low) requirements on the location it will make it into first choice. However a project with good economics and bad requirement rating will not.

Additionally other validation criteria are taken into account, such as overall potential of an energy source, ecological footprint, efficiency and technical risks.

3 Introduction

3.1 Introduction – Possible applicable oil and gas technology in the renewable energy sector

In the uprising energy crisis more and more oil and gas companies set their focus also on producing renewable energy. BP for example is the number one photovoltaic cells producer in the world; Halliburton has implemented the largest research algae biomass reactor. In areas of beneficial geologic character drilling engineering is used to make geothermal energy assessable.

But are there other possibilities for a classic oil and gas producing company in the renewable energy sector (like in this example RAG), making use of their core competences, which can be defined as:

1.) Drilling Engineering
2.) Production Engineering
3.) Reservoir Engineering
4.) Gas Distribution
5.) Gas Storage

3.2 Introduction - Market situation: Renewable energies

There are basically two types of energy that can be supplied, heat energy and electric energy. Market situation is fundamentally different for both types.

3.2.1 Introduction – Market situation: Renewable electric energy

The electric energy supply from renewables is federal supported in two ways (in Austria and Germany). The electric network operator is forced to buy at a predefined price and at any time the renewable electric energy is produced.

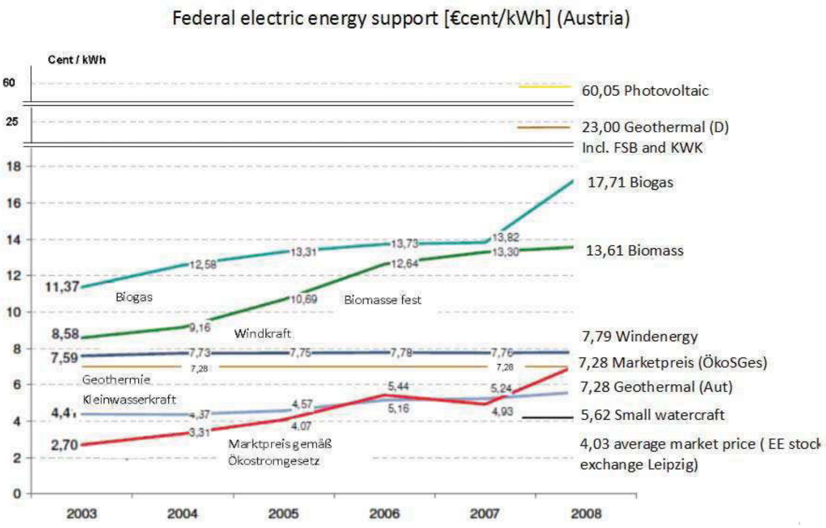


Figure 2: *Federal electric energy support [1]*

Illustrated is the development of the yearly average federal supported renewable energy prices in Austria, compared to the marked price after "Ökostromgesetz" and stock exchange value according to "Leipziger Strombörse". In Germany the values are quite comparable in the majority of cases, even though most of the time higher and more complex calculated. A main difference is the high support of geothermal electric energy with 230 €/MWh compared to 72, 8 €/MWh in Austria.[1]

This graphic was presented in Austria's "Ökostrombericht 2008", one conclusion was that small watercraft and wind energy is close before being competitive. One should be aware of, that this graph does not represent necessary federal investment assistance, neither takes into account if an energy source can support base load. For example wind energy would be in need of much higher support if the network operator would not be forced to buy output at any time.

In summary it can be stated that the fixed price and assured buy off of electric energy, makes various alternative electric energy producing systems economic under certain circumstances. The legislator aims to support only reasonable energy supply systems. If, for example a process delivers electric energy and heat energy, the price support on electric energy is (should) only (be) given, if a certain amount of the heat energy is also used. Additionally the value of the supported price is designed in a way that a project can just be competitive, if this is done. Exact values and more detail information will be given later on - project type specific.

The characteristics of renewable electric energy can be summarised

1.) Guaranteed buy off
2.) Guaranteed price
3.) Normally fast, easy and relatively cheap adaptable to supply network

3.2.2 Introduction – Market situation: Renewable heat energy

As mentioned the situation in the renewable heat energy supply is fundamentally different, there is neither a price guarantee nor an assured buy off. Renewable heat energy suppliers are in an open marked competition with concurring energy. Additionally a heat distribution network is not only quite expensive to build, but also takes time, delaying revenue. One the one hand, to construct the network itself, on the other hand until potential customers connects to it.

In case that, the renewable energy supplier is also the operator of a heat energy network, price needs to be designed in a way being competitive to concurring energies. Otherwise the price is negotiated with the network owner.

The characteristics of renewable electric energy can be summarized

1.) No guaranteed buy – off – open market situation
2.) No guaranteed price – open market situation
3.) Usually the development of a distribution network delays revenues

3.2.3 Introduction - Project Types

The research for reasonable projects in which the core competences of a classic oil and gas company could be used yielded following main types of projects:

1.) Geothermal wells for generating heat energy
2.) Geothermal wells for generating heat and electric energy
3.) Geothermal wells supporting other Heat and Electric Energy Supplier
4.) Subsurface heat energy storage
5.) Subsurface electric energy storage – CAES (Compressed Air Energy Storage) – system*
6.) Subsurface CO_2 Storage**

Despite from a few exceptions most project types will be dependent from the ability to supply heat energy (primarily or additionally). According to this, the work will be built up in the steps described in “Evaluation and predesign of an energy concept - Overview”.

**Briefly touched*

***Not discussed in this work*

4 Evaluation and predesign of an energy concept – Overview

1.) **Strategic preliminary decisions**
   a. Selection of fitting location and time
   b. Requesting interest from main potential customers
   c. Pricing and financing
   d. Marketing and information in concerned community

2.) **Legal point of view**
   a. Federal support
   b. Juridical requirements

3.) **Heat Energy demand analysis and prognosis**
   a. Amount of energy (and power) demand
   b. Distribution of energy (and power) demand over a year (demand line)
   c. Distribution of energy (and power) demand concerning geographic situation and network
   d. Possible acquisition of customers

4.) **Selection and pre dimensioning of**
   a. Energy supplying system type
   b. Heat energy distribution network variants
   c. Customer adaption

5.) **Optimizing of the total system**
   a. Basic economic evaluation
   b. Optimizing of energy supplying system and distribution
   c. Project "Stress check"
   d. Sensitivity analysis

The different topics will be discussed in general and specific according to the evaluation software. Formal this work will always present a topic theoretical in the first place. If required, the way, how the software handles the discussed problems is presented directly afterwards. Those sequences concerning the evaluation software will always be marked with a pre head *"Evaluation Software".*

After basic information in general and evaluation software specific is provided, investigated project types will be presented.

5 Evaluation software- Overview

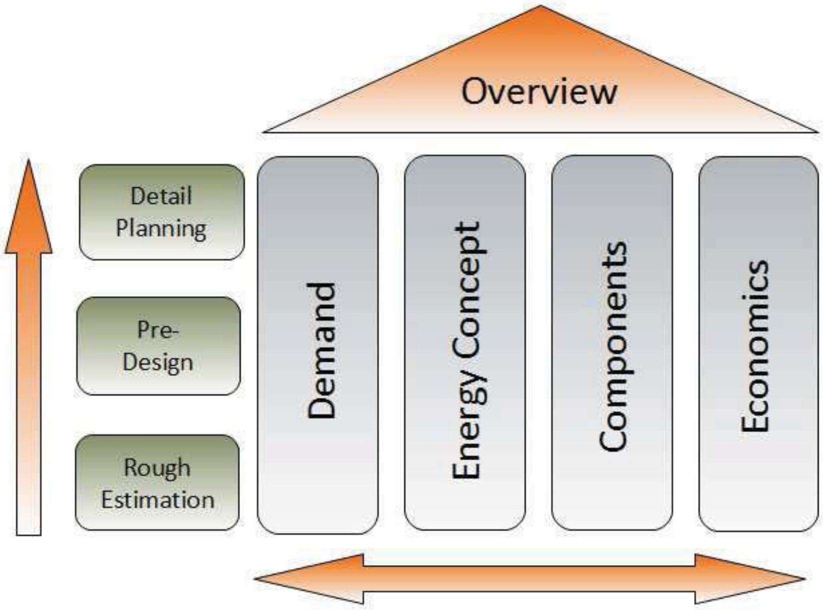


Figure 3: *Evaluation software basic description [own illustration]*

Illustrated is the basic set up of the program. Four main modules receive and compute data, importing it to the module "Oversight". The orange double arrow on the base represents the iterative optimization process. Input of one main module will influence total results and therefore settings in other modules. The orange upward arrow on the left represents the different planning steps; the software offers quick and more time consuming detailed ways of importing and evaluating data.

The evaluation software is designed according to the illustration. There are basically four base programmes (columns) that can take and evaluate data, importing it to an "overview spread sheet" The programmes are separated in a way that each value can be changed in the overview spread sheet, without disturbing formulas in the main programmes.

Most base programmes offer various ways of importing data, from very quick rough ones for estimations to relatively time expensive more exact data input, that allows also a project predesign. In a few cases (Network and biogas power plant) it is possible to export data to professional software, which even would make a detail planning possible (with additional data available). But in the majority of cases the program does not support planning beneath a predesign!

Planning Phases

1.) Estimation
2.) Pre design
3.) Detail planning

5.1 Evaluation software - Brief description of main modules

5.1.1 Overview

1.) Main project control such as:
    a. Location (Temperature data, country)
    b. Project start (Influence on cost functions and energy price)
    c. Basic heat distribution network settings
    d. Economic settings
    e. Others
2.) Import and export data from main programmes (and separate results from them – for being freely changeable)
3.) Visualising information
4.) Economic evaluation (+ Project stress check)
5.) Providing data for fine tuning and sensitivity analysis (every value can be changed by hand to observe project reactions – additionally an automatic spider chart creator is supported, which changes every chosen value by a predefined percentage and plots changes on predefined important values. Such as internal rate of return or total energy efficiency.)

5.1.2 Demand

1.) Total energy demand of different required heat energy types
    a. Heating energy
    b. Domestic water
    c. Other energy
2.) Distribution of demand over a year
3.) Development of the demand over the project life time
4.) Necessary network costs

As the electric energy output is not in need of demand, due to the forced buy off it is not considered in this base program.

5.1.3 Energy concept

1.) Type and size of energy support
2.) Operation type
3.) Starting and ending years
4.) Embedded storage systems

This base programmes provides specific

1.) Evaluation programmes
2.) Cost functions
3.) Efficiency functions
4.) Others

For

1.) Geothermal water producing wells (capable of producing just heat or heat and electric energy)
2.) Geothermal heat producing wells
3.) Biomass power plants
4.) Heat pumps
5.) Boiler for oil, gas, wood products
6.) Storage systems
7.) (Slot for other energy suppliers with known data)

5.1.4 Economics

Fine tuning and sensitivity evaluation of variables on economic reference numbers providing spider charts, as described in “Overview” point 5. (Rough stress checks are embedded directly in “Overview”)

6 Evaluation and predesign of an energy concept – Strategic preliminary decisions

6.1 Selection of fitting location and time

Depending on the project type naturally the location plays a major role. Some important factors concerning

1.) Distribution network
    a. Settling type, energy demand density / existence of major costumers
    b. Necessary temperature.
    c. Topographic situation

2.) Energy supply
    a. Amount of produce able energy (available biomass, depth / permeability of geothermal structure, etc. -depending on project type)
    b. Necessary investment and operation costs (price for biomass, sun energy per square meter per year, depth of geothermal well etc. - depending on project type)

Another important factor is to choose the right project starting time, for example construction costs for a heat energy distribution system might change up to 20% from one year to another, and same applies to other components. It also might be that federal support is dependent of being online before or after a certain date. Other reasons could be that major costumers plan to set measurements to save energy, or on the other hand major new potential customers might appear.

6.2 Requesting interest from main potential customers

It might easily be that smaller projects are dependent on a few major costumers, it is crucial to evaluate their interest, price suggestions, total demand, demand peaks, demand distribution over a year, and also planned changes within the project life time.

6.3 Pricing and financing

There are various systems of energy pricing. Basically they are split in two major components, on the one hand there is the price per MWh of energy delivered, and on the other hand a construction subsidy is demanded.

6.3.1 Customers connection behaviour

It is absolutely necessary to design the pricing and financing system with great care. (In smaller projects maybe even individually for each object) Too high costs will keep the customers from attaching to the network (or at least delay), however naturally low prices will fall back on the economics.

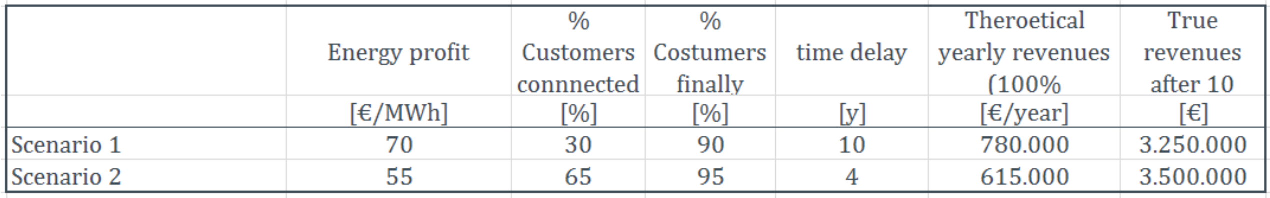
Example

To visualise the importance of a fast customer acquisition a brief example is given.

500 single family homes shall be connected to a geothermal well. This would yield and energy demand of 11.200 MWh per year (all customers connected). It is assumed that the network is completed within one year, the heat energy price is constant and the connection to the network follows a logarithmic function. The energy price already includes operation costs.

Further an internal rate of 10% was anticipated.

Two Scenarios are chosen



	Energy profit	% Customers connnected	% Costumers finally	time delay	Thereotical yearly revenues (100%	True revenues after 10
	[€/MWh]	[%]	[%]	[y]	[€/year]	[€]
Scenario 1	70	30	90	10	780.000	3.250.000
Scenario 2	55	65	95	4	615.000	3.500.000

Figure 4: *Scenario settings and results*

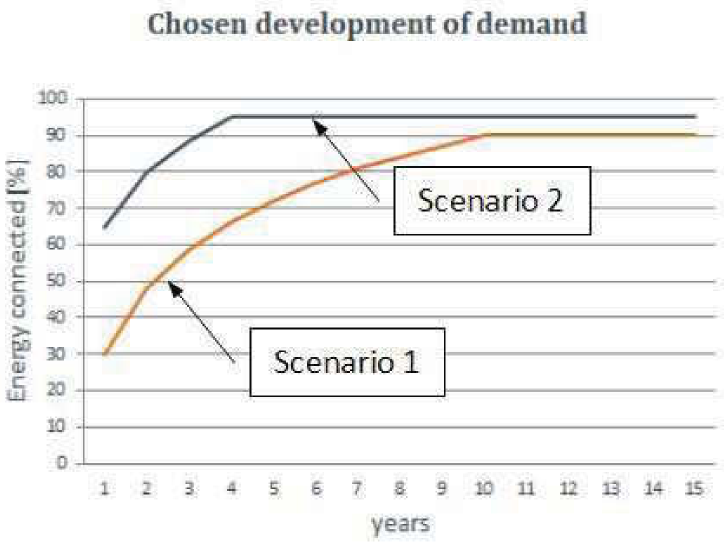


Figure 5: *Graphic illustration of customer connection behaviour [own illustration]*

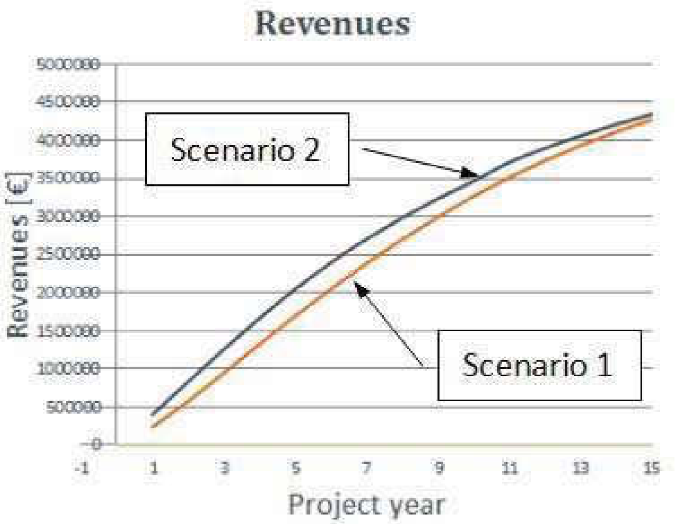


Figure 6: Graphic illustration of resulting cumulative revenues [own illustration]

As illustrated in this example, if the profit per sold MWh is cut down by 30 %, approximately the same project value is reached after fifteen years, as if the connection delay is reduced as described.

Technical problems originating from slow costumer connection behaviour

In addition a slow development of the requested energy also makes it hard to choose the right size of the energy supplier. In most cases a module wise installation will become necessary.

Construction subsidy vs. Energy price per MWh

Another important tool is the balancing of energy price and construction subsidy. Distribution networks have been financed up to 70% by subsidies accepting low profits per MWh. In this work financing strategies will not further be touched, as they are complex and individually different.

Owner - user dilemma

At this point the “owner – user dilemma” also shall be mentioned. Even the best pricing system will normally not convenience a flat building owner to invest money to safe heating costs for his tenants. On the other hand tenants maybe don’t want to invest in heating systems which go to the property of the house owner, and needs years for amortisation. Problems of this kind need to be considered with specialised offers.

6.4 Heat energy prices

As mentioned, the pricing system of every project has to be developed individually with great care. Following number is only a very rough approximated average value: 45 – 85 €/MWh are heat energy prices that usually can be expected. However it needs to be considered, that bigger customers are likely to demand a lower price, as well this price is not suitable if heating systems, where own wood, or other local cheap available energy sources are used, needs to be pushed out.

6.5 Evaluation software - Heat energy prices

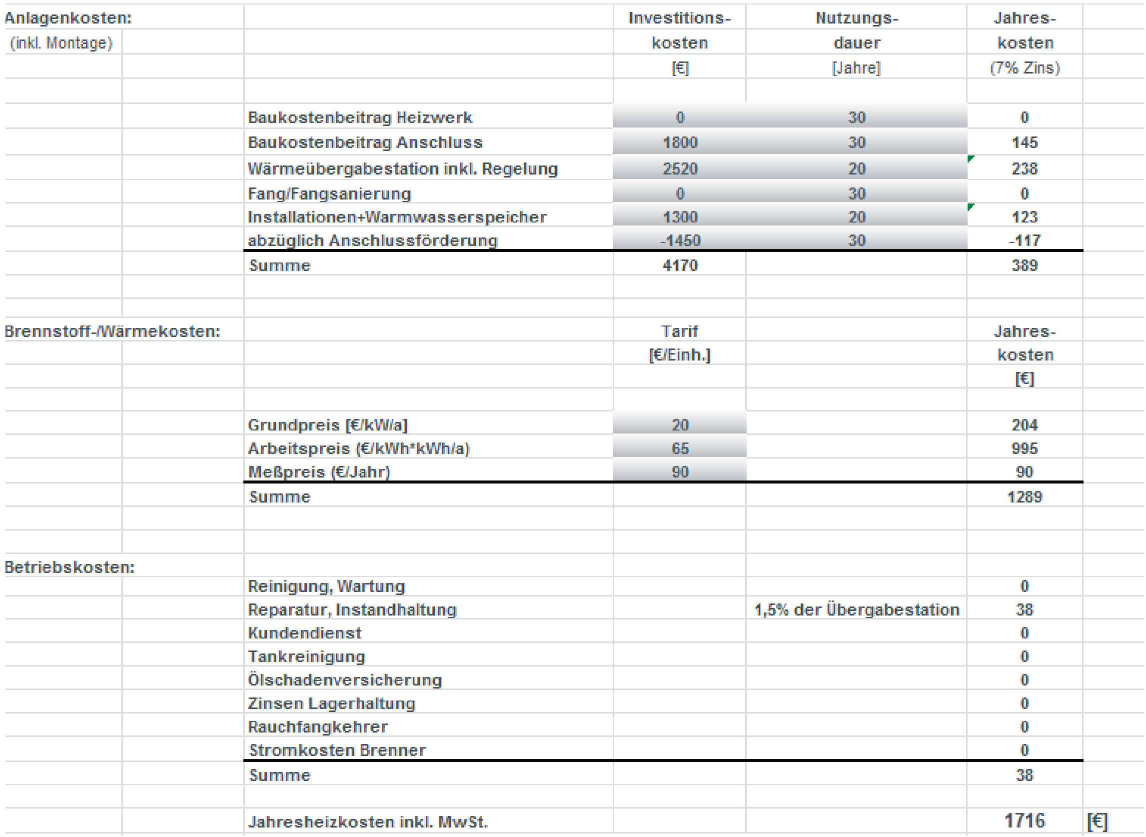
(Extern included Program from [2])

The Excel Tab File “Heizkosten Berechnung” offers basic assistance in comparing the yearly costs for different energy systems and predefining a heat energy price.

As illustrated in Figure 7 , costs are diverted into:

1.) Investment Costs
2.) Energy Costs
3.) Operating Costs

The investment costs are calculated back, over an internal rate of return and the lifetime of the component to gain the costs per year. Investment cost, energy costs and operating costs are added up to yield the yearly energy costs, as illustrated in the example for a heat distribution network



Anlagenkosten: (inkl. Montage)		Investitions- kosten [€]	Nutzungs- dauer [Jahre]	Jahres- kosten (7% Zins)	
	Baukostenbeitrag Heizwerk	0	30	0	
	Baukostenbeitrag Anschluss	1800	30	145	
	Wärmeübergabestation inkl. Regelung	2520	20	238	
	Fang/Fangsanierung	0	30	0	
	Installationen+Warmwasserspeicher	1300	20	123	
	abzüglich Anschlussförderung	-1450	30	-117	
	Summe	4170		389	
Brennstoff-/Wärmekosten:		Tarif [€/Einh.]		Jahres- kosten [€]	
	Grundpreis [€/kW/a]	20		204	
	Arbeitspreis (€/kWh*kWh/a)	65		995	
	Meßpreis (€/Jahr)	90		90	
	Summe			1289	
Betriebskosten:					
	Reinigung, Wartung			0	
	Reparatur, Instandhaltung		1,5% der Übergabestation	38	
	Kundendienst			0	
	Tankreinigung			0	
	Ölschadenversicherung			0	
	Zinsen Lagerhaltung			0	
	Rauchfangkehrer			0	
	Stromkosten Brenner			0	
	Summe			38	
	Jahresheizkosten inkl. MwSt.			1716	[€]

Figure 7: *Heat energy price evaluation spread sheet – calculates yearly costs for different heating systems [own illustration]*

A similar calculation sheet is prepared for:

1.) Oil heating
2.) Gas heating
3.) Wood pellets heating
4.) Geothermal energy + Heat pump

As mentioned these heat energy prices are only applicable if the energy supporter is also the operator and owner of the distribution network. If a renewable energy source is built for an existing network, the achievable prices are much lower, as the network owner can dictate them to some degree.

Please note that this part of the software is completely copied form C.A.R.M.E.N e.V. imbuing my standard formatting on it.

6.6 Marketing and information in concerned community

“Modern district heating concerns of one third technic one third politics and one third psychology”

[Fritz Ringele, 1st. president of Refuna AG]

In the past projects were ruined due to problems with neighbours, for various reasons. Obviously it is difficult to convince people to attach to a community heating, if the energy source is annoyingly loud or smelling. Other problems might occur if rights for pipelines or fuel transportation are needed in neighbouring properties.

Even already running systems can be brought down by annoyed neighbours, in some cases civic action groups were founded, that invested time and money to bring plants successfully down.

Everything should be done to avoid these problems!

Due to individual perception people have subjective perspectives, therefore the same topic is judged very differently within a community. Energy supplier should try to understand the individual views of concerned persons. (For example noise from a biogas plant, can be not even recognized by one neighbour, while another is already taking juristic action)

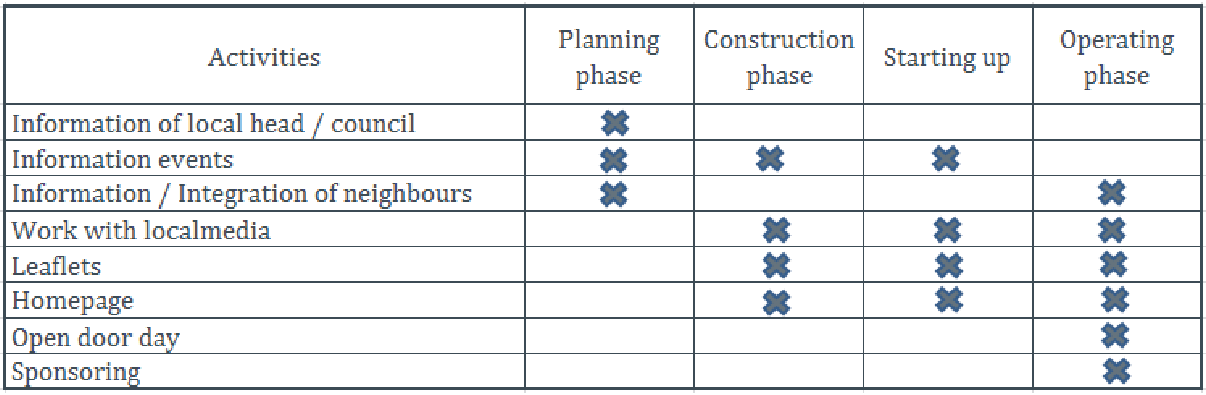
It is absolutely necessary to argue objective and honest. It is always better to admit that some things are not completely clear (yet), than promise things that cannot be realised later. A broken promise will not be forgotten, and the energy supplier loses trust and integrity. [Modified according to 3]

There can be very good arguments for local energy solutions

1.) Interesting heat energy pricing
2.) Money spent for energy stays at least partially in the region, not as usual goes completely to over regional energy concerns
3.) Up valuation of properties (existing buildings and land property)
4.) Other pipelines might be installed parallel to the community heating network to split costs (especially in new settlement areas)
5.) Ecological aspects
6.) Prestige and publicity of local politicians and community itself

It pays back to honestly communicate advantages and problems of a planned project to concerned persons!

The following is a cut down rough summary of a communication adviser published by “Österreichisches Lebensmittelministerium”



Activities	Planning phase	Construction phase	Starting up	Operating phase
Information of local head / council	✖			
Information events	✖	✖	✖	
Information / Integration of neighbours	✖			✖
Work with localmedia		✖	✖	✖
Leaflets		✖	✖	✖
Homepage		✖	✖	✖
Open door day				✖
Sponsoring				✖

Figure 8: *Communication advisor – Information activities during project lifetime [own illustration modified according to [3]*

6.7 Heat energy demand analysis and prognosis

[Information of Chapter 11.7 is taken from 4 and 5]

6.7.1 Types of heat energy demand

Basically the heat energy demand is split into three main groups

1.) Heating energy
2.) Domestic water
3.) Other demand (industrial water, etc.)

6.7.2 Gaining information about required heat energy

There are three possibilities to gain information about energy demand

4.) Calculation according to (e.g. [DIN 4701])
5.) Surveys
6.) Averaged values for building types

The average part of domestic water demand was about 17% in the 80’s. Due to improved building technology the required heating energy was reduced by 30% since then. In modern low energy homes the domestic heat energy is just about 50% of the total energy.

After the total demand of energy is by whatever means evaluated, it is required to know, how the demand is distributed over the year.

6.7.2.1 Distribution of heating energy demand over a year (demand line)

Heat energy is assumed being proportional to outside temperature. If temperature data is available the demand line can be constructed. Two other values also need to be mentioned which are important in Austria's and Germanys technical regulations. The "Normwärmebedarf" which represents the maximum value that needs to be supported (e.g.: The temperature value of a certain region, outside temperature drops beneath four times in 20 years). The second important value is the "Heizgrenztemperatur", which represents the outside temperature at which the heating systems are switched off (different from room temperature)

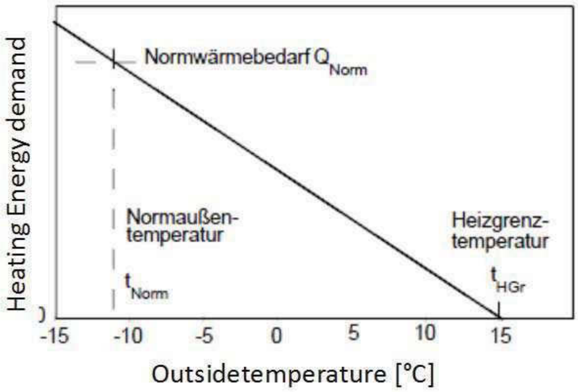


Figure 9: Dependence of heating energy demand form outside temperature [4]

Illustrated is the assumed direct proportionality of heating demand on outside temperature. "Normwärmebedarf" shows the lowest outside temperature the system is designed for. Heating demand at "Heizgrenztemperatur" (15°C) is zero, even though it is lower than room temperature (e.g. 20°C)

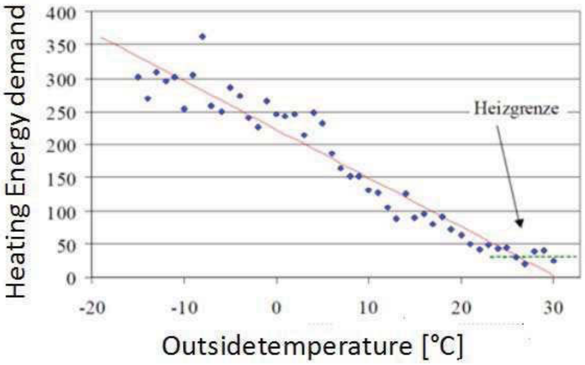


Figure 10: Heat demand depending on outside temperature [5]

Illustrated is the result of a measurement in a community heating system located in Tamsweg (Salzburg) – Testing Interval 1hour, recording period 1 month, 155 costumers

6.7.3 Distribution of domestic water demand over a year

Total domestic water demand does not change a lot over the year, but has strong daily peaks, the importance of these peaks on the overall system are dependent on two major influences. First, the amount of connected buildings – the more users the more peaks even out. And secondly on the installed heating system, basically there are two possibilities, direct flow through heating and heating with a storage (boiler) system included. (Will be discussed in more detail)

6.7.4 Distribution of total energy demand over a year

If both energy types are defined in value and distribution they can be sorted according to size and represented in a graph.

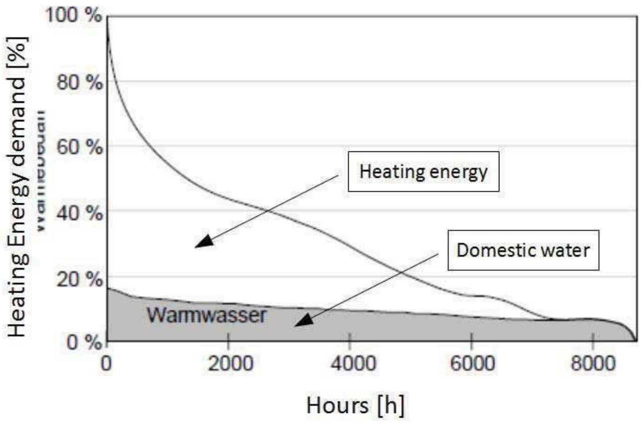
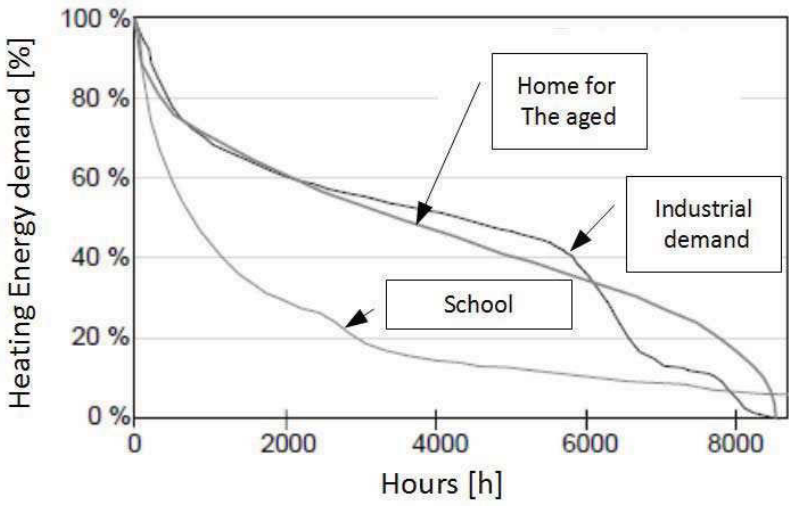


Figure 11: *Distribution of total energy demand over a year (Demand line) [4]*

Illustrated is an example of a heating energy and domestic water demand distribution over a year. (For a single family home)



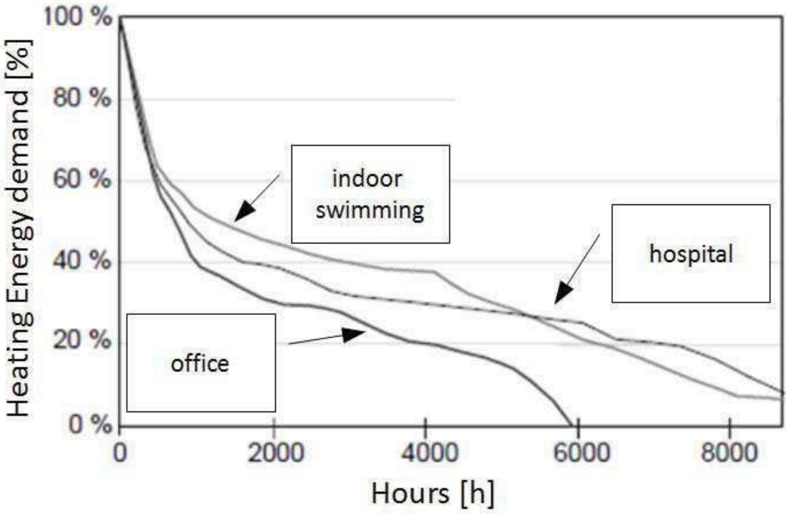


Figure 12: *Energy demand distribution for selected buildings. (Demand line) [Modified according to 4]*

Please note that the x – Axis has nothing to do with the calendric order of days, it is purely sorted according to demand. If daily values are used for example.: 1st of January, 31th December, 2nd January, 30th December, and so on leading to days in spring represented next to days in fall.

If for example a customer requires large amount of energy in spring (public bath) it makes no sense to simply sort the data, the additional required energy has to be added or differently considered in a rational and logical way – not just being sorted by software!

The sorted demand line is enough to pre design the energy supply system, but there is no information about daily or weekly peaks, without a detail planning is impossible

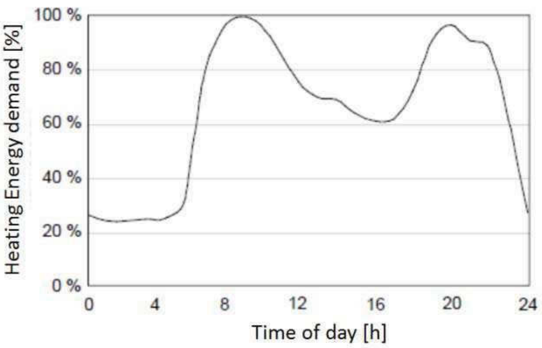


Figure 13: *Daily peak in domestic water demand [4]*

Illustrated as an example of important information the energy distribution over the year (demand line) does not contain. Daily storage systems (boilers) and type of network operation might (will) be influenced by it

7 Distribution of energy (and power) demand concerning geographic situation and network

Modern community heating networks are normally built as two pipeline system with water as energy carrier media (forward and backward flow pipe). In exceptions two forward flow pipes with a common or even two backward flow pipes are used. [4]

7.1 Main distribution

The structure of the networks main distribution is governed by given circumstances of the settlement structure (geographic distribution of buildings, streets, rivers, etc.), by the networks size, and amount and location of energy sources.

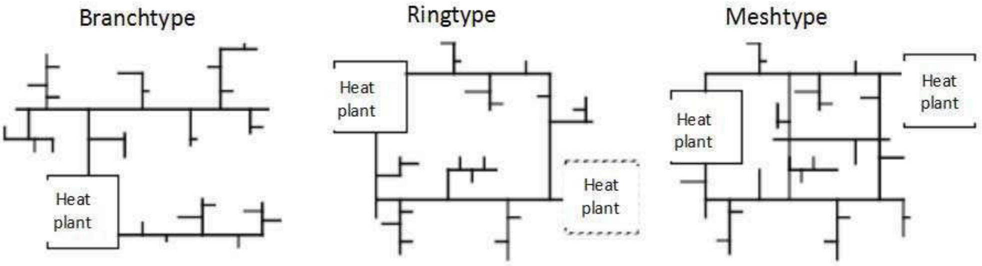


Figure 14: *Illustration of different main distribution network types [4]*

Please note that there can be only one location for a heat energy source in the branch type network. Additionally the operation safety is reduced as if a branch fails all sub branches are also concerned. Only advantage is lower costs due to lower pipelines required.

For small and medium sized community heating networks branch type network will be preferred, as they require lowest pipeline length. Ring type networks allow the connection of more than one energy source in different locations, they will also offer better operation safety, but at higher costs (longer pipeline length and no reduction in diameter of main pipe). Optimum safety and expandable potential is offered by mesh type systems. [4]

7.2 Sub distribution and adaption of buildings

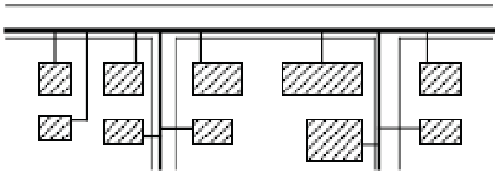


Figure 15: *Sub distribution: Standard*

The greatest flexibility is offered by the most often applied standard sub distribution type, every costumer is separately connected to the network. However, resulting in high investment costs due to amount of required pipes itself and fittings. [Corresponding to 4]

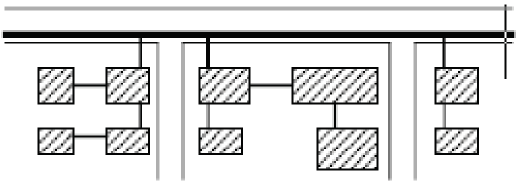


Figure 16: *Sub distribution: House to house*

In the house to house sub distribution houses are summarized in groups, one house is directly connected to the main distribution network, to which the others are attached. Under certain circumstances there is fewer pipe length and fewer fittings (especially for branches from main pipeline) required. As the pipes are situated in house owners property allowances are needed. [Corresponding to 4]

In a row house settlement the house to house sub distribution switches to the special type “cellar to cellar sub distribution” which offers very low investment costs and easy access for reparation. [4]

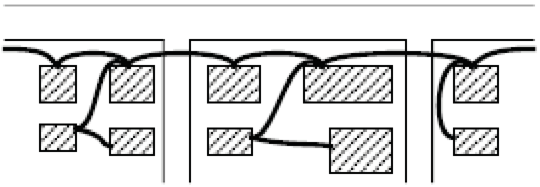


Figure 17: *Sub distribution: Flexible pipes (“Einschleifmethode”) [4]*

Another applied technique that can be used in combination with flexible pipes is the “Einschleifmethode”. There is no separated main and sub distribution, all customers are connected by flexible pipes as illustrated. Even though flexible pipes are more expansive than standard ones, it might easily be that this type requires lowest investment cost, as very little fittings are required and pipe length can be reduced. The main disadvantage is that the network can hardly be enlarged once build up. [4]

Planner should be aware of the fact, that none of the described types is automatically the cheapest, as it depends on the given circumstances. Most often standard or a combination of standard and house to house type is chosen. For small closed networks in special cases sometimes also “Einschleifmethode” [corresponding to 4]

7.3 Dimensioning – Optimization of network

7.3.1 Pipe diameter

Optimum pipe diameter is governed by two influences, one the one hand material and construction costs reduces with smaller diameter, on the other hand pressure losses and therefore operating costs (pump costs) increase. Additionally pipes attaching to home heating stations have to be dimensioned according to maximum allowed noise emission, which depend on pipe diameter (velocity of fluid). [4]

The optimum pipe diameter can just be found by an exact simulation including following factors. A few will be discussed in more detail

1.) Forward and backward flow temperature
2.) Operation type
3.) Network losses
4.) Simultaneity factors
5.) Type of home stations (size of included storage)
6.) Geodetic height
7.) Net structure
8.) Pipe roughness
9.) Material and electricity costs

7.3.2 Forward and backward flow temperature

Low backward flow temperatures are fundamentally important for the operation costs of a community heating system. For several reasons:

1.) Lower pumping costs or smaller pipe diameter

2.) Reduction of energy losses

3.) Usage of low temperature energy for backflow preheating

Low backflow temperatures can be achieved in homes with low temperature heating systems. Another possibility is a multistage usage of the heating energy, where the backflow from one costumer is used (direct or slightly increased by additional energy) as the forward flow for another costumer with lower required temperature.

7.3.3 Pumping costs

The difference between forward and backward flow temperature governs the amount of energy that can be transported in a pipe with a certain diameter.

$$V = \frac{Q}{c} * (Tf - Tb)$$

***Equation 1**: Volumetric flow*

$$v = \frac{V}{(r^2 * \pi)}$$

***Equation 2:** Average velocity*

$$dp = \lambda * \frac{L}{d} * \frac{\rho}{2} * v^2$$

***Equation 3:** Pressure loss*

$$\lambda f(\frac{d}{k}, Re, FR)$$

***Equation 4:** Pipe friction factor*

$$P = dp * V / \acute{\eta}$$

***Equation 5:** Pump power*

V = Volumetric flow [m³/s], Q = Heat flow [W],c = Heat coefficient [J/kgK],Tf Forward flow Temperature [K], Tb = Backward Flow Temperature [K], v = average velocity [m/s], r = pipe radius [m], dp = pressure loss [Pa], λ = pipe friction coefficient [], L = length of pipe [m], d = Diameter of pipe [m], ρ = density [g/m³],k=pipe roughness [m],Re=Reynolds number [], FR =Flow Regime [], ή = Pump efficiency []

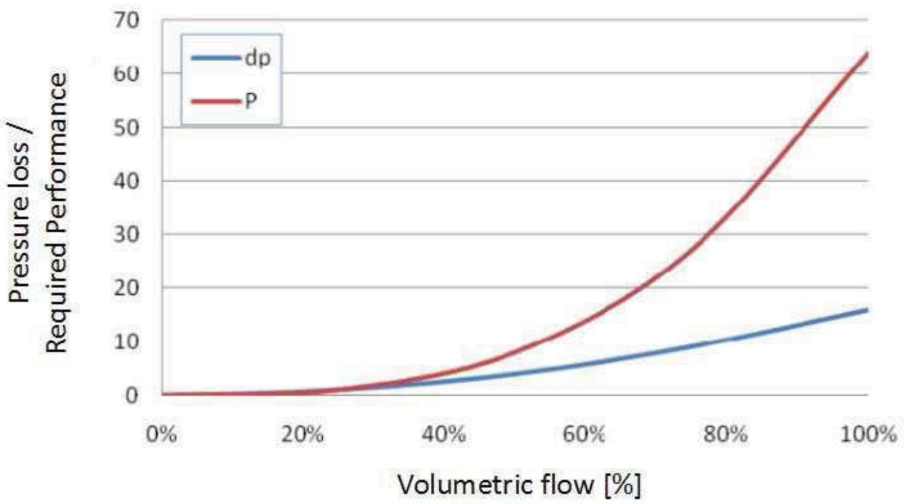


Figure 18: *Required Pump performance vs. volumetric flow [own illustration]*

This graph reflects the increased necessary pumping power if the energy transmission through a pipe is increased by increasing volumetric flow, instead of higher Temperature difference (neglecting temperature caused changes in density and viscosity)

In other words if the energy that is pumped through a pipe shall be doubled there are basically two possibilities: Increasing the volumetric flow or increasing the difference between forward and backward flow temperature. If the volumetric flow is doubled the pump pressure losses and therefore energy consumption are (~) quadruplet. Doubling the temperature difference has compared relatively little influence (due to viscosity and density changes) on the pump pressure.

7.3.4 Operation type

The operation type is an appliance of the described possibility to increase the carried energy in a given pipe diameter by increasing the forward temperature, during high demand. This operation type is called “Temperature controlled” in opposition to “Mass flow controlled” regulation.

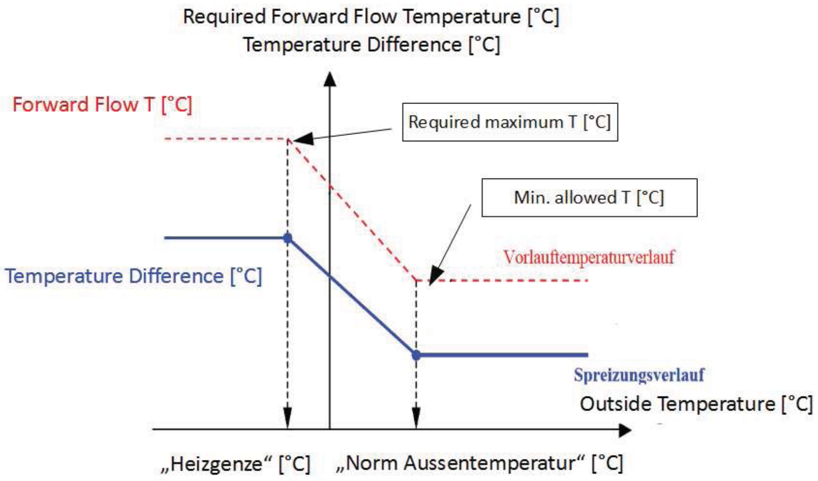


***Figure 19**: Temperature controlled operation type [modified according to 6]*

Illustrated is an example of a temperature controlled network operation. According to the outside temperature the forward flow (red) and therefore the temperature difference (blue) is increased.

7.3.5 Limitations of “Temperature controlled” regulation

1.) Maximum produce able temperature (Geothermal wells, storage systems)
2.) Maximum transportable temperature (Maximum allowable T of pipes, boiling point of heating media)
3.) Increased temperature also means increased energy losses

In practise a mixture of both regulation types is applied. Please note that the system losses during summer are relatively higher than in winter. This is due to the increased time the heating media has to stay within the system (reduced flow speed), especially for short peak demand it makes sense to use the “mass flow” controlled system, whereas seasonal differences are controlled by Temperature regulation. However the energy supplier may be forced to use a “mass flow” controlled system if the energy source is not capable to deliver energy above a certain level, same applies to limitations of maximum allowed pipe temperature and boiling point of heating media.

7.3.6 Necessary temperature levels for utilizing heating energy

Temperature was discussed according to its influence on transportable energy and therefor network operation mode. Limitations such as maximum allowed temperature in pipes or maximum produce able temperature by suppliers were also touched.

At this point temperature demand for different costumers will be covered.

7.3.7 Temperature levels for home heating stations

As usual the topic has to be evaluated from two different points of views:

1) Heating energy temperature level
2) Domestic water temperature level

Heating energy

The heating energy temperature level is governed by the heating system of the house. Standard old fashioned heating systems run with a f/b-T (forward/backward temperature) from 80 - 95 °C / 55 - 45°C. Studies have shown that most homes can be heated with a f/b –T of 60 to 30 °C due to over dimensioned heating systems. However this has to be evaluated individually. There are network providers, who allow customers to connect only if they can run their heating system with a predefined low f/b T. of 60/30 °C. Sometimes improvement of the homes isolation is necessary to accomplish the needs.

Low temperature systems in low energy homes can be run with F/B T of 35 / 25 °C and lower.

Domestic water energy

Temperature level of domestic water energy is governed by hygiene requirements. As a rule of thumb it can be stated, to limit the growth of bacteria: “Cold water should be cold and hot water should be hot”. Therefore it is tried to avoid storing domestic water in the temperature window between 10 and 55 °C.

A forward flow of at least 60°C is required to full fill governmental requirements in Austria and Germany.

Especially bacteria of the Legionellae species have caused problems in the past. Note that an infection via the skin or by drinking is impossible. Only breathing water aerosol for example in showers, will cause infections.

7.3.7.1 Other temperature levels for various costumers

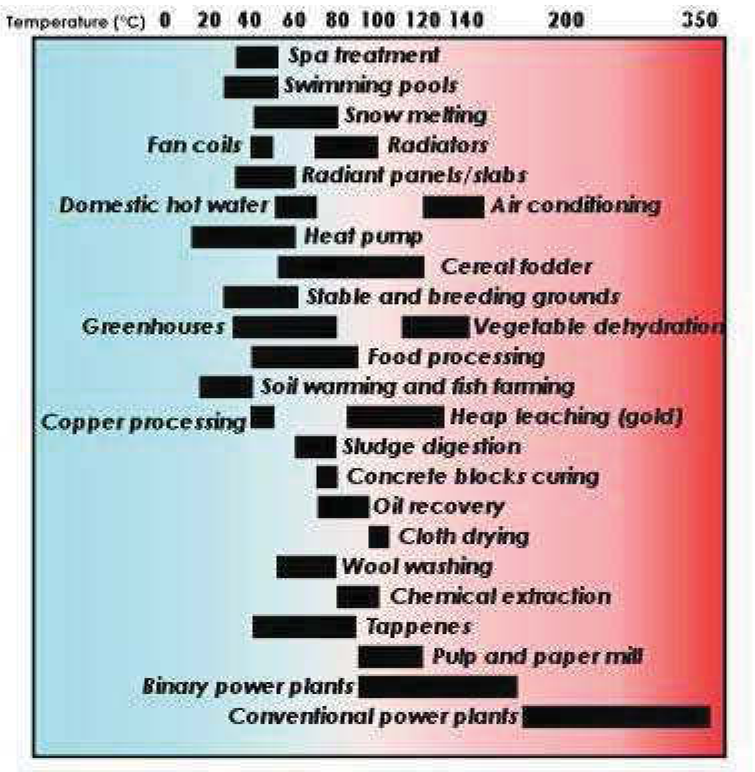


Figure 20: *Lindsay diagram – Required temperature level for different applications [unknown source – website inactive]*

Due to the discussed renewable electric power market situation, most alternative energy providers will try to turn high level heat energy into electric power, and utilize only the power plants back flow for heating applications.

Economically interesting is the possibility of using the backflow temperature of the first network for other costumers (= Cascade). Theoretically this would be possible for following low temperature energy takers:

1.) Heat pump
2.) (Public) swimming pools
3.) Greenhouses
4.) Stable and breeding grounds
5.) Soil warming
6.) Fish farming

Especially the usage of geothermal energy in spas is traditionally strong in Upper Austria. In my opinion rest energy is seldom utilized in agriculture.

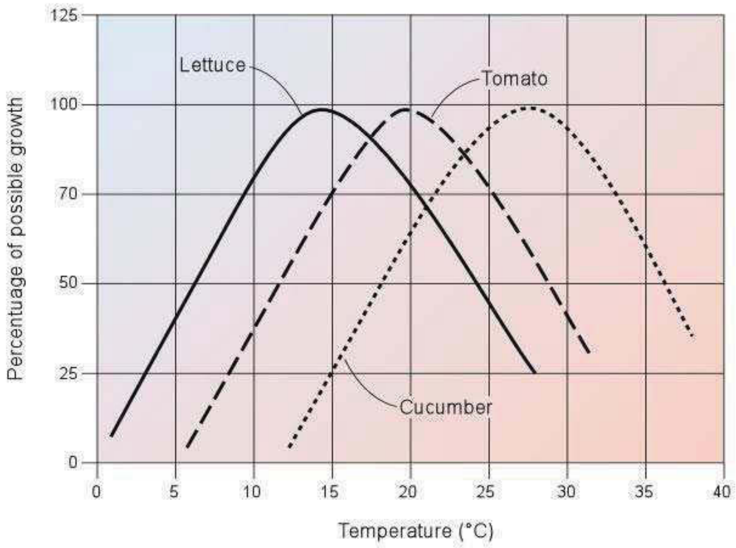


Figure 21: *Growth curve for some crops [unknown source– website inactive]*

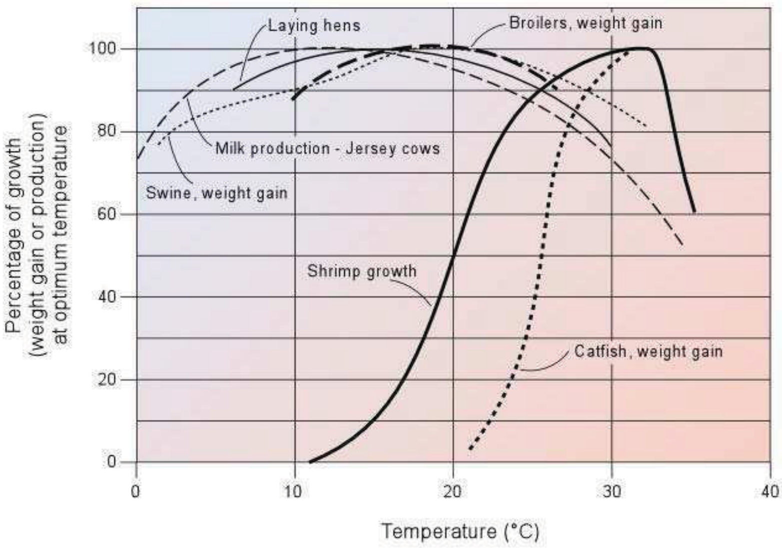


***Figure 22**: Growth curve for some food animals [unknown source– website inactive]*

In a renewable energy project it should always be tried to utilize as much heating energy as possible. The benefits of a two or more stage cascade usage in heating systems of different F/B temperatures should not be underestimated. Communication and information of local farmers should be done early in the project.

My personal opinion is that also hydro culture of algae and bacteria will become more and more important in (far) future, as they are able to produce various industrial products at low temperature level and up to 10 times more biomass than any land plant. Maybe these nowadays rather unknown costumers will take low level renewable energy in future.

7.3.8 Simultaneity factors

Due to temporal spreading of individual peak loads in community heating systems, the maximum thermal power demand is lower than the sum of the individual nominal power of its heat costumers. This effect is called “Simultaneity” and is described by the “Simultaneity factor” which is fundamentally important for correct design (concerning network AND energy supply plants).

Definition simultaneity

$$S = \frac{\sum_{i=1}^{m} P_i(t)}{\sum_{i=1}^{m} P_{N,i}}$$

Equation 6: *Definition of simultaneity [5]*

S = Simultaneity Factor [], m= number of costumers (of approximately equal demand) [], Pi (t) Performance of costumer, t = time (e.g. [hours], [days]),

For dimensioning of the required maximum pipe diameter the maximum required performance is essentially

$$S = \frac{\sum_{i=1}^{m} P_i(t_{max})}{\sum_{i=1}^{m} P_{N,i}}$$

Equation 7: *Definition of Simultaneity at maximum performance [5]*

The main factor influencing the simultaneity factor is the number of customers (m). For dimensioning the pipelines of course only the customers that are attached on the examined hydraulic path are taken into account.

Simultaneity factors are different according to the type of energy and house station types (size of storage)

Simultaneity factor for heating energy

Several studies yielded functions that describes these factors, for this thesis and the attached software the function from “Untersuchung der Gleichzeitigkeit in kleinen und mittleren Nahwärmenetzen [Walter Winter]”, was used.

It was gained by investigating Austrian community heating systems with a few 100 customers. It can be assumed that the influence of typical heating systems technical regulations and customer behaviour are to some extend reflected.

$$SF(m) = a + \frac{b}{1 + (\frac{n}{c})^d}$$

Equation 8: *Simultaneity factor [5]*

SF=Simultaneity factor [], m = Number of costumers [], a=0, 44968 [], b=0, 55123[], c=53, 8438[], d=1, 76274[], Function valid for 1<m<200, (coefficient of determination *r^2=0.95)*

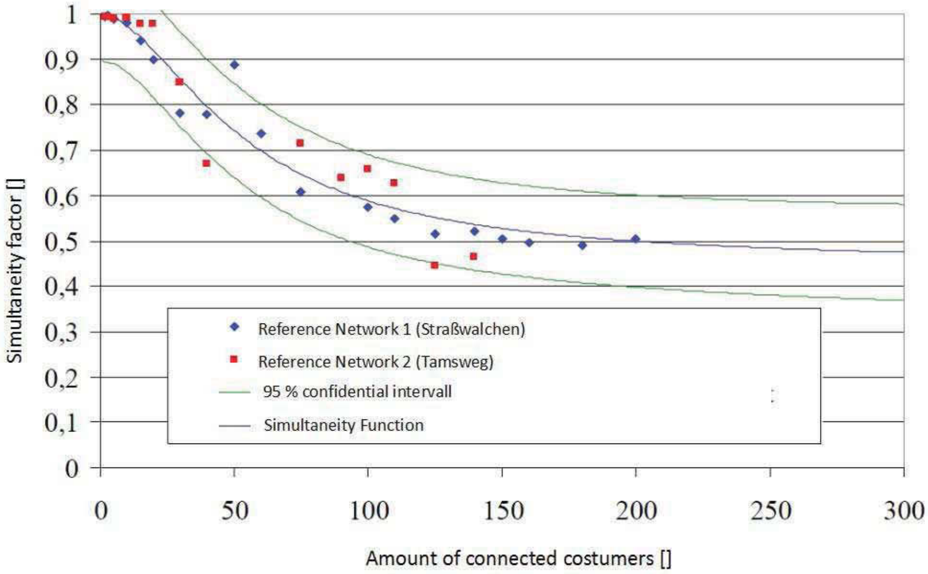


Figure 23: *Simultaneity factor function tested in a reference networks [5]*

It should be noted that these function is only valid for heating demand and for customers of approximately equal size (!)

In other words, if one customer takes 50 % of the demand and 39 others share the other 50 % the calculated simultaneity factor for 40 customers will not apply.

Domestic water simultaneity factors

Please note that not only heating demand and domestic water demand apply different simultaneity factors, but also for domestic water demand not always the same functions can be applied. Domestic water preparation systems which includes storage, reduces peak load significant, but the storage charging lasts longer and therefore the simultaneity effect is reduced. (Summing up both effects storage systems will nevertheless always require lower maximum power, even though this effect reduces with increasing number of costumers)

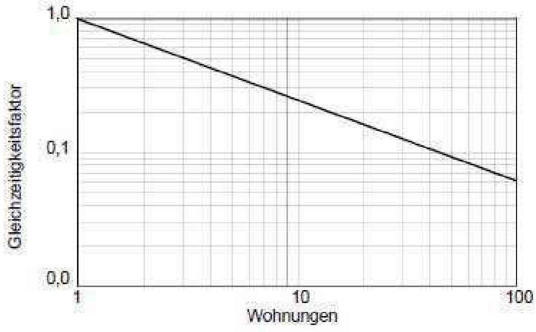


Figure 24: *Simultaneity factor for domestic water (storage system) [4]*

In classic applications, the domestic water peak load does not influence the overall design of the network too much (concerning type, diameter of pipelines and size of energy supplier). Therefore it can be represented as a constant load throughout the year, or by given functions that can be found in literature.

7.3.9 Type of home stations

The home station is the connection between the community network and the home heating system. It consists of the heat transmission station (property of the network owner) and the house station (property of customer). The transmission station regulates and controls the contractual agreed heat supply; concerning: Pressure, Forward and backward flow temperature. [Corresponding to 4]

House stations regulate heat energy quality for the requirements of the homes heating system (Temperature and pressure). [Corresponding to 4]

Modern community heating systems offer standard sized home stations which include all components; they can be installed within half a day. [4]

Please not that costs for home stations can be up to 50 % of the total costs of a network.[4]

Types of heating home stations

In principal there are two main types of home stations, the direct type, in which the heating media of the community heating network is directed to the heating system of the home. (Temperature can be reduced mixing backflow water by). The second main type is the indirect type – Heat is exchanged by a heat exchanger between network and home heating system. [Corresponding to 4]

The basic advantage of the indirect system is the independency of network pressure and water quality of the network. Direct systems offer lower investment. However the network heating media might be polluted during reparation on home heating systems or old house installations. [Corresponding to 4]

Due to the increased safety especially if handling with high network pressure most companies prefer installation of indirect systems. However, having fitting network parameters the cost saving potential of direct systems should be considered. [Corresponding to 4]

Types of heating home stations - including preparation of domestic water

Domestic water preparation can be done with three different systems.

<u>Flow through system</u>

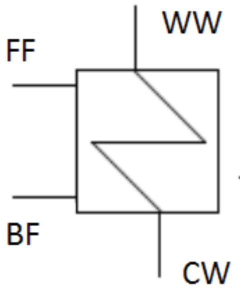


Figure 25: *Flow through system [4]*

The incoming heat is directly exchanged in a plate heat exchanger, therefore peak demand is quite high, can however be reduced due to domestic water simultaneity factors. This system can also be installed as 2 stage type, where in the first step the heating backflow water is used for preheating. [4]

<u>Advantages:</u>

1.) Low investment costs
2.) No storage of warm water <–> bacteria growth
3.) Low achievable backflow temperatures
4.) Small Investment costs and footprint

<u>Disadvantages</u>

1.) Higher required power – partially evened out due to simultaneity

Storage system

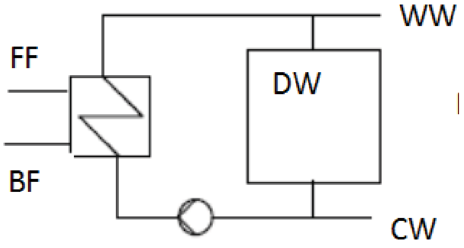


Figure 26: *Storage system [4]*

Incoming heat energy is transferred via a heat exchanger to the houses heating water, which is stored in a boiler. Backflow temperature is higher, because during charging storage water temperature rises until finally backflow temperature is nearly equal to storage temperature. [Corresponding to 4]

Advantages

1.) Lower required maximum power

Disadvantages

1.) Higher backflow temperature
2.) Higher investment costs larger footprint
3.) Bacteria growth if not used longer time

Flow through storage system

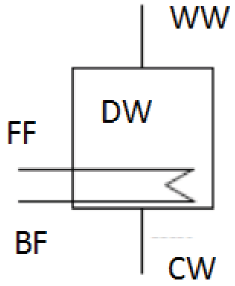


Figure 27: *Flow through storage system*

This system is a combination of both types. The heat exchanger supports the average heat demand; peak load is carried by stored water, charged in times of low demand. [Corresponding to 4]

Advantages

1.) Low required maximum power
2.) Average low backflow temperature achievable

Disadvantages

1.) High investment costs / large footprint
2.) Increased steering expense

For large amount of domestic water preparation most commonly used is the storage flow through system. Smaller requirements are fulfilled with the storage system, and only for very small demand a flow through system is installed.

Influence on required power- Example:

50 households compared flow through and storage system

Required energy: 5, 8 kWh (standard power requirement for homes = filling a bath tub)

Direct flow through system filling time 10 min -> ~ 36 kW connections

140l storage (boiler) recharges time 60 min -> ~ 10 kW connections

Total Demand (FT) = 36 50 = 1800 kW*

*Total Demand (SS) = 10 * 50 = 500 kW*

Applying the different simultaneity factors the difference evens out with increasing amount of costumers.

The direct flow heating system requires more power and therefore larger diameters. Taking simultaneity factors into account this effect is unchanged (relatively). But the absolute values shrink considerable, it needs to be checked individually if and a how much larger diameter is required. According to literature values for an amount of 40 costumers only approximate 16% larger diameter is required. [Corresponding to 4]

Especially if large numbers of customers are connected the flow through system should have a chance to be the preferred choice. However, as mentioned pure direct flow through systems are in practice seldom applied. [Corresponding to 4]

7.4 Pipe line construction costs

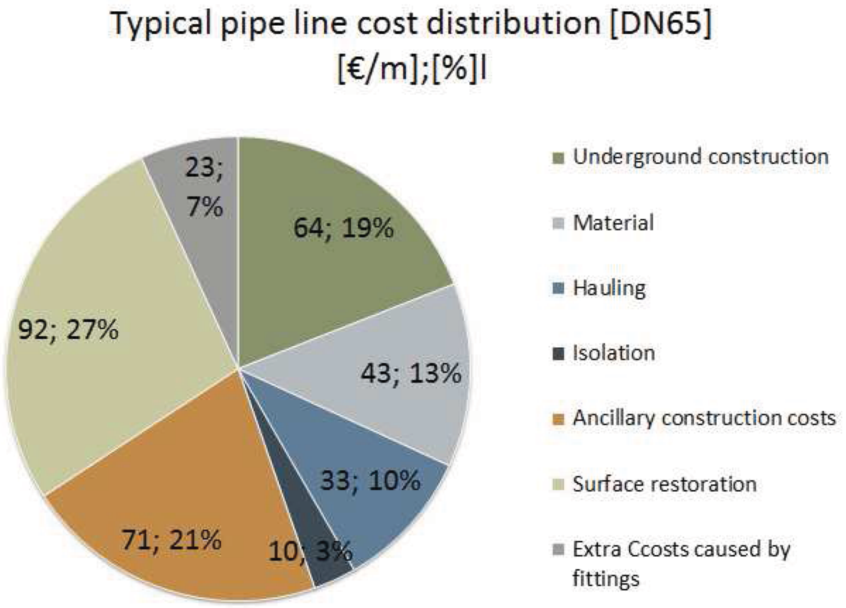


Figure 28: *Pipe line cost distribution [own illustration information according to 4]*

As illustrated in Figure 28 surface restoration is approximately 13 % of the total costs, which would drop for a pipeline constructed in green land. Extra fittings required for crossways with different pipes will cause approximately 7% of the costs. Underground construction is about 20 % which would not apply, if the network is built up together with other lines. (All percentages also include their part on ancillary construction costs) Summarizing it can be stated, that it makes a big difference in which terrain a pipeline is constructed, this should be considered in cost estimations.

8 Evaluation software - Demand

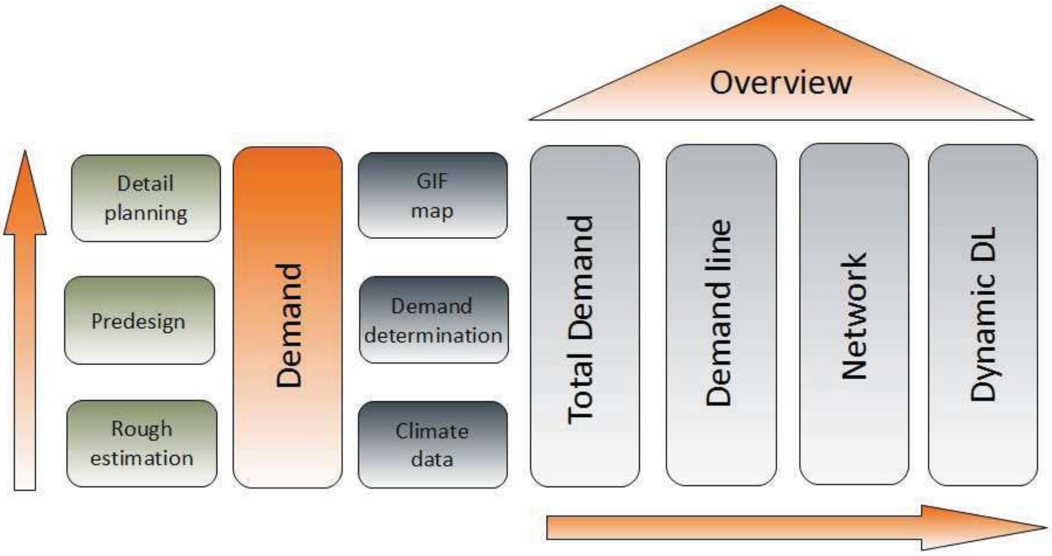


Figure 29: *Build-up of main program "Demand". [Own illustration]*

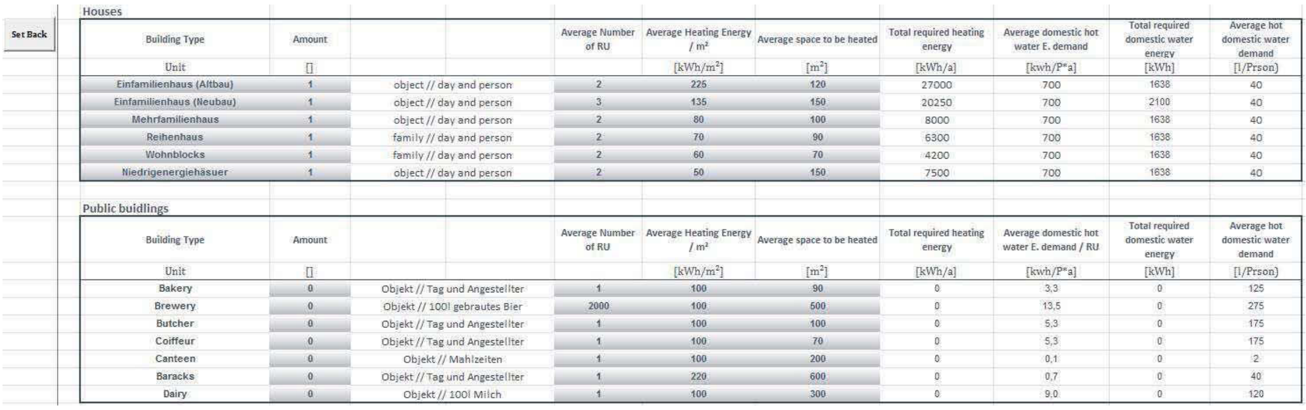
The program part concerning heat energy demand is split in four basic modules, helping to define: the total heating energy demand, the demand line, necessary network, and the dynamic demand line – in other words the demand line changes throughout the project years. DL = Demand Line

8.1 Evaluation software - Total demand

According to the planning phase data can be processed different.

8.1.1 Heating energy demand input for rough estimations

In a first attempt average and estimated values can be used



Houses

Building Type	Amount		Average Number of RU	Average Heating Energy / m²	Average space to be heated	Total required heating energy	Average domestic hot water E. demand	Total required domestic water energy	Average hot domestic water demand
Unit	[]			[kWh/m²]	[m²]	[kWh/a]	[kwh/P*a]	[kWh]	[l/Prson)
Einfamilienhaus (Altbau)	1	object // day and person	2	225	120	27000	700	1638	40
Einfamilienhaus (Neubau)	1	object // day and person	3	135	150	20250	700	2100	40
Mehrfamilienhaus	1	object // day and person	2	80	100	8000	700	1638	40
Reihenhaus	1	family // day and person	2	70	90	6300	700	1638	40
Wohnblocks	1	family // day and person	2	60	70	4200	700	1638	40
Niedrigenergiehäsuer	1	object // day and person	2	50	150	7500	700	1638	40

Public buidlings

Building Type	Amount		Average Number of RU	Average Heating Energy / m²	Average space to be heated	Total required heating energy	Average domestic hot water E. demand / RU	Total required domestic water energy	Average hot domestic water demand
Unit	[]			[kWh/m²]	[m²]	[kWh/a]	[kwh/P*a]	[kWh]	[l/Prson)
Bakery	0	Objekt // Tag und Angestellter	1	100	90	0	3,3	0	125
Brewery	0	Objekt // 100l gebrautes Bier	2000	100	500	0	13,5	0	275
Butcher	0	Objekt // Tag und Angestellter	1	100	100	0	5,3	0	175
Coiffeur	0	Objekt // Tag und Angestellter	1	100	70	0	5,3	0	175
Canteen	0	Objekt // Mahlzeiten	1	100	200	0	0,1	0	2
Baracks	0	Objekt // Tag und Angestellter	1	220	600	0	0,7	0	40
Dairy	0	Objekt // 100l Milch	1	100	300	0	9,0	0	120

Figure 30: *Estimation of total demand, based on average values for building types [own illustration]*

The software offers several predefined heat energy demands for buildings; additional energy can be added by type and amount.

8.1.2 Heating energy demand input required for predesign

Even though not directly cited, the part of the software utilizing Open Jump was done on the basis of Michael Dewein's work [7]

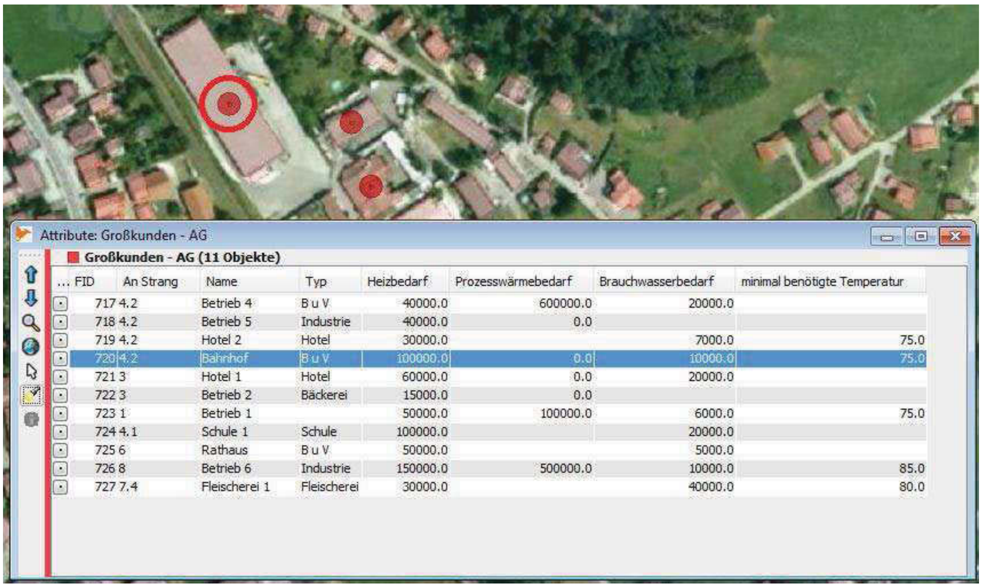
More information can be included using the additional geo information software "Open Jump". A map is imbued with information for each object, while geometrical data such as areas can be automatically calculated by Open Jump.

There are two possibilities to imbue data on buildings

1.) Specific data for single buildings (bigger costumers)
2.) Specific data for buildings of the same type

The program is also able to handle mixtures of these data input types

Specific data for single buildings



Attribute: Großkunden - AG

Großkunden - AG (11 Objekte)

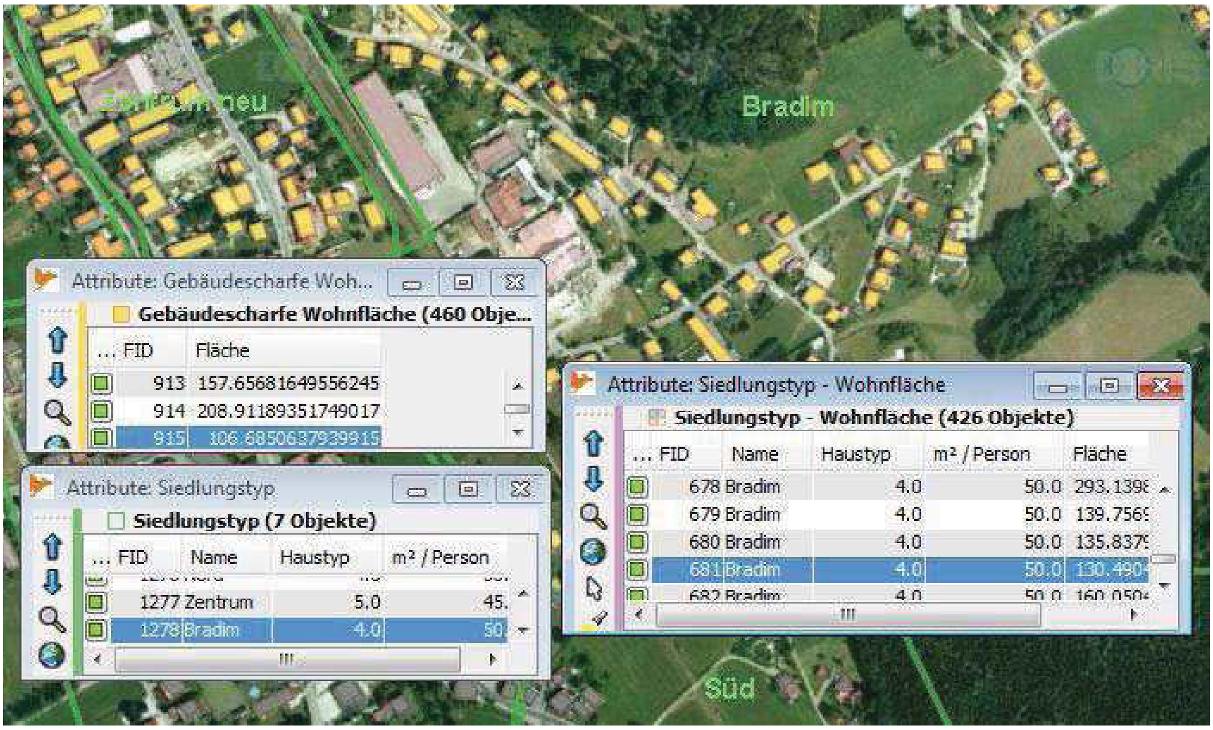
... FID	An Strang	Name	Typ	Heizbedarf	Prozesswärmebedarf	Brauchwasserbedarf	minimal benötigte Temperatur
717	4.2	Betrieb 4	B u V	40000.0	600000.0	20000.0	
718	4.2	Betrieb 5	Industrie	40000.0	0.0		
719	4.2	Hotel 2	Hotel	30000.0		7000.0	75.0
720	4.2	Bahnhof	B u V	100000.0	0.0	10000.0	75.0
721	3	Hotel 1	Hotel	60000.0	0.0	20000.0	
722	3	Betrieb 2	Bäckerei	15000.0	0.0		
723	1	Betrieb 1		50000.0	100000.0	6000.0	75.0
724	4.1	Schule 1	Schule	100000.0		20000.0	
725	6	Rathaus	B u V	50000.0		5000.0	
726	8	Betrieb 6	Industrie	150000.0	500000.0	10000.0	85.0
727	7.4	Fleischerei 1	Fleischerei	30000.0		40000.0	80.0

Figure 31: *Specific data input for single buildings [own illustration]*

Storable attributes: Name; Type;Heating energy demand; Domestic water demand; Other energy demand and minimum required temperature

As can be seen heat, domestic water and other energy demand can be directly stored. (Other data like building type, minimum Temperature and Number of pipeline it is connected to will be discussed later on)

Specific data for buildings of the same type



Attribute: Gebäudescharfe Woh...

Gebäudescharfe Wohnfläche (460 Obje...

... FID	Fläche
913	157.65681649556245
914	208.91189351749017
915	106.6850637939915

Attribute: Siedlungstyp

Siedlungstyp (7 Objekte)

... FID	Name	Haustyp	m² / Person
1277	Zentrum	5.0	45.
1278	Bradim	4.0	50

Attribute: Siedlungstyp - Wohnfläche

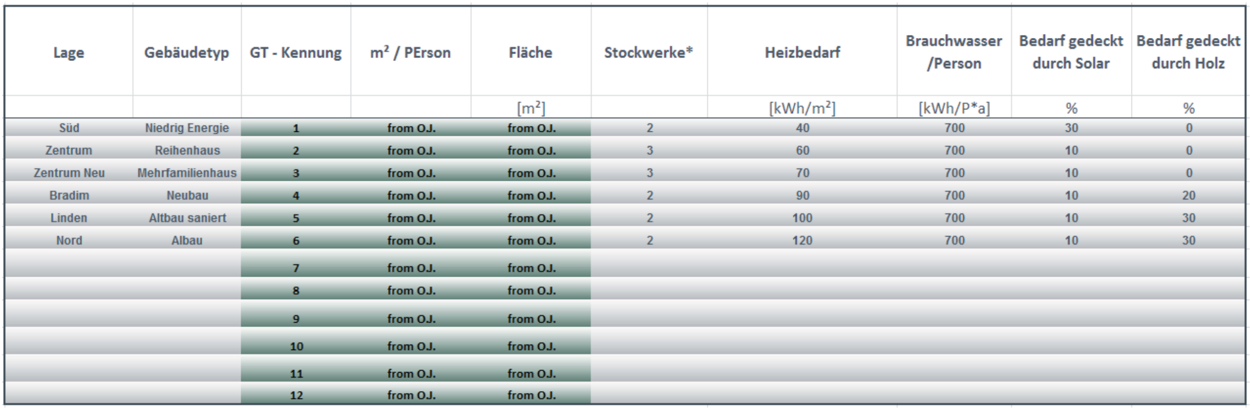
Siedlungstyp - Wohnfläche (426 Objekte)

... FID	Name	Haustyp	m² / Person	Fläche
678	Bradim	4.0	50.0	293.139
679	Bradim	4.0	50.0	139.756
680	Bradim	4.0	50.0	135.837
681	Bradim	4.0	50.0	130.490
682	Bradim	4.0	50.0	160.050

Figure 32: *Specific data for buildings of the same type [own illustration]*

Storable / Calculated data: Name of area; House type; Living space per person; Living space

The program calculates the projected area of each building, areas of the same building type, like in the example “Bradim” can be marked and the attributes: house type and m²/person can be imbued on every building. This data is exported to the evaluation software where the house types are further defined. (kWh/m², numbers of floors, etc.).



Lage	Gebäudetyp	GT - Kennung	m² / PErson	Fläche	Stockwerke*	Heizbedarf	Brauchwasser /Person	Bedarf gedeckt durch Solar	Bedarf gedeckt durch Holz
				[m²]		[kWh/m²]	[kWh/P*a]	%	%
Süd	Niedrig Energie	1	from OJ.	from OJ.	2	40	700	30	0
Zentrum	Reihenhaus	2	from OJ.	from OJ.	3	60	700	10	0
Zentrum Neu	Mehrfamilienhaus	3	from OJ.	from OJ.	3	70	700	10	0
Bradim	Neubau	4	from OJ.	from OJ.	2	90	700	10	20
Linden	Altbau saniert	5	from OJ.	from OJ.	2	100	700	10	30
Nord	Albau	6	from OJ.	from OJ.	2	120	700	10	30
		7	from OJ.	from OJ.					
		8	from OJ.	from OJ.					
		9	from OJ.	from OJ.					
		10	from OJ.	from OJ.					
		11	from OJ.	from OJ.					
		12	from OJ.	from OJ.					

Figure 33: *Definition of reference numbers chosen in Open Jump [own illustration]*

The data input from Open Jump can further be defined in this excel sheet. (E.g. Reference Number 1, refers to: House type name “Niedrigenergiehaus”, Number of floors: 2, *heating demand: 40 kWh/m², Domestic water per person 700 kWh/P*a; Demand already covered by solar panels: 30 %)*

The total heat and domestic and other energy demand is than calculated (summed up), according to the data. Additional, it can be taken into account that heat demand is partly covered by wood fireplaces or solar panels. (Adding solar will reduce domestic water demand, wood reduces heat energy)

8.2 Evaluation software – Construction of demand line

8.2.1 Heating and domestic water energy

As discussed in the general part, heating energy is proportional to outside temperature. The software offers a number of reference locations especially in Upper Austria (major operation area of RAG) but also in rest of Austria and Bavaria. Please note that own data can be used, to do this, the tab "eigene Klimadatei verwenden" has to be ticked on. The data should consist of 364 average daily temperature values, and has to be copied in predefined cells

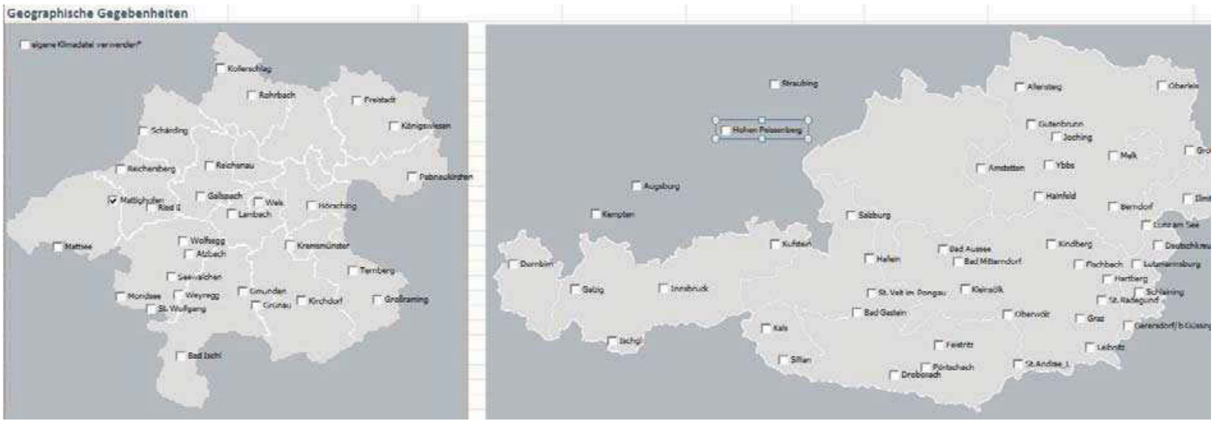


***Figure 34**: Input sheet: Climate data [own illustration]*

The program will display the resulting temperature distribution over a year. (Minimum and average daily values)

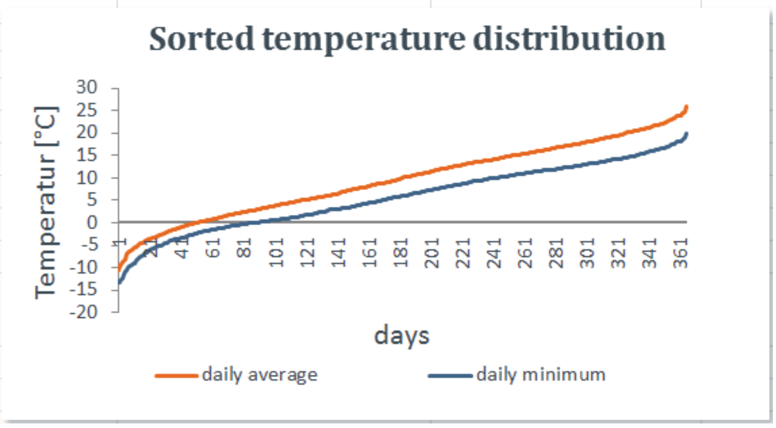


Figure 35: *Sorted temperature distribution [own illustration]*

Eingabe o.k.

	Referenzort	Projektort	Daten
Projektort = Referenzort ☐ Ja	FELDKIRCHEN_MATTIGHOFEN	Munderfing	Munderfing
Seehöhe**	528	468	468
Normaussentemperatur***	-10,9	-11	-11
Heizgrenzwert mittlere Tagestemperatur	16	16	16
Heizgrenzwert minimale Tagestemperatur	12	12	12

**eigene Klimadatei muss in "Eingabe Klimadatei" eingefügt werden*

***Wenn Rerenzort nicht dem Projektort entspricht.: Klimadaten werden automatisch zum Referenzort höhenkorrigiert + - 0,01°C / m*

****Nach DIN - kann nach ÖNORM tiefer liegen - gegebenefalls im Projektort korrigieren*

Figure 36: *Additional Input concerning climate data and heating energy [own illustration]*

If the desired location is not to choose and no own data is available, a nearby location can be picked, the program will generate a temperature data set according to the Adria height difference.

The influence of the values “Normaussentemperatur” and “Heizgrenzwert” were already discussed. In this program the heating energy demand can be switched off according to the daily minimum or a daily average, as there are different point of views in the literature (heat energy demand will turn to zero if one of the values is reached)

According to the input data also the “Heizkennzahlen” graph is displayed.

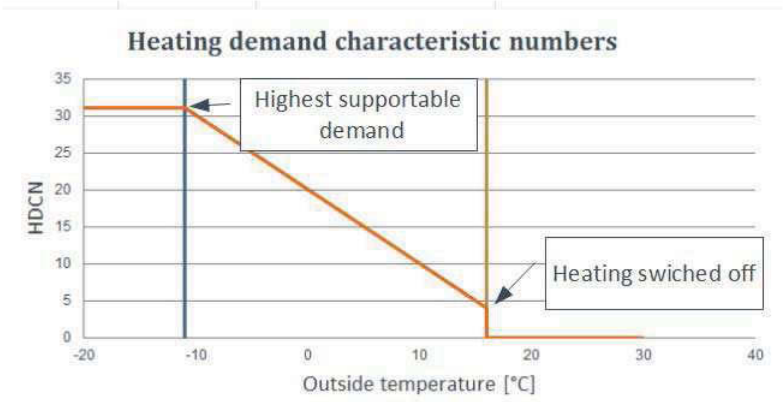


Figure 37: Heating demand – characteristic numbers (line) [own illustration]

Finally the program calculates a heating demand for every day according to the formula

$$req.HeatEnergy(d) = Total\ req.Heat\ Energy * \frac{HDCN(d)}{\sum_{1}^{364} HDCN}$$

Equation 9: *Required heating energy*

Energy [MWh]; HDCN = Heating demand characteristic number [°K]

In a further step the resulting data is sorted according to its size. Domestic heat energy is added as pure constant base load, yielding a heat energy demand line. (Additional demand for other costumers must be added by hand)

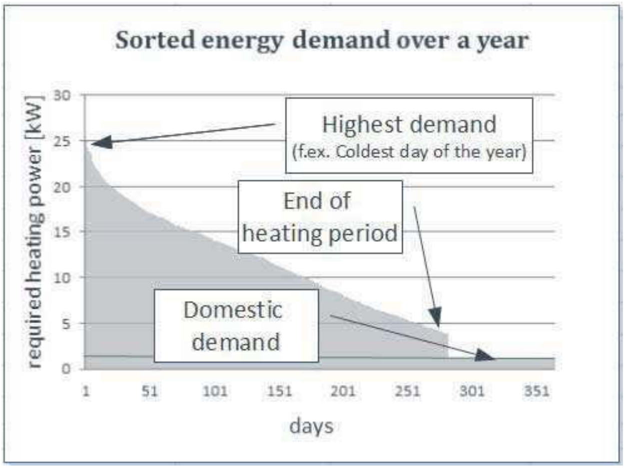


Figure 38: *Demand line [own illustration]*

Illustrated is a demand line consisting of heating and domestic water energy. The influence of the parameters "Heizgrenzwert" and "Normaussentemperatur" can be seen clearly

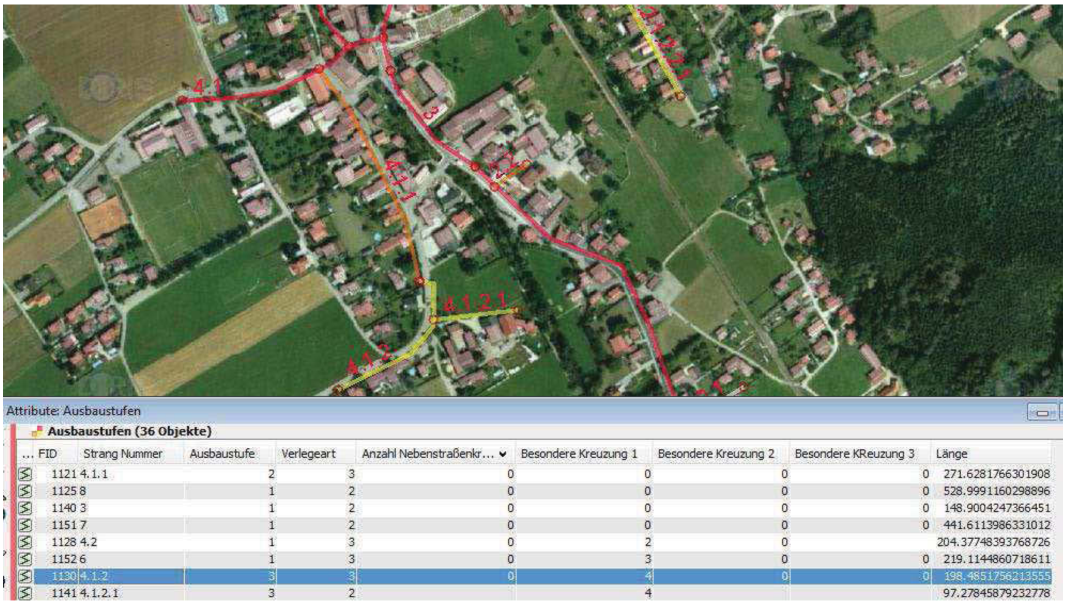
This graph is the very basis for the planning of an energy supply system.

8.3 Evaluation software - Network

Target of this part of software

1.) Approximation of network costs
2.) Relative comparison of network types
3.) Helping deciding if it pays off to connect a certain area
4.) Investigate the impact of demand delay due to network construction
    a. Technical (fitting energy support in every project year)
    b. Economic impact (delayed revenue)

The data is directly input into the existing geo information map, pipes are drawn with the "line" tool



... FID	Strang Nummer	Ausbaustufe	Verlegeart	Anzahl Nebenstraßenkr...	Besondere Kreuzung 1	Besondere Kreuzung 2	Besondere KReuzung 3	Länge
1121	4.1.1	2	3	0	0	0	0	271.6281766301908
1125	8	1	2	0	0	0	0	528.9991160298896
1140	3	1	2	0	0	0	0	148.9004247366451
1151	7	1	2	0	0	0	0	441.6113986331012
1128	4.2	1	3	0	2	0		204.37748393768726
1152	6	1	3	0	3	0	0	219.1144860718611
1130	4.1.2	3	3	0	4	0	0	198.4651756213555
1141	4.1.2.1	3	2		4			97.27845879232778

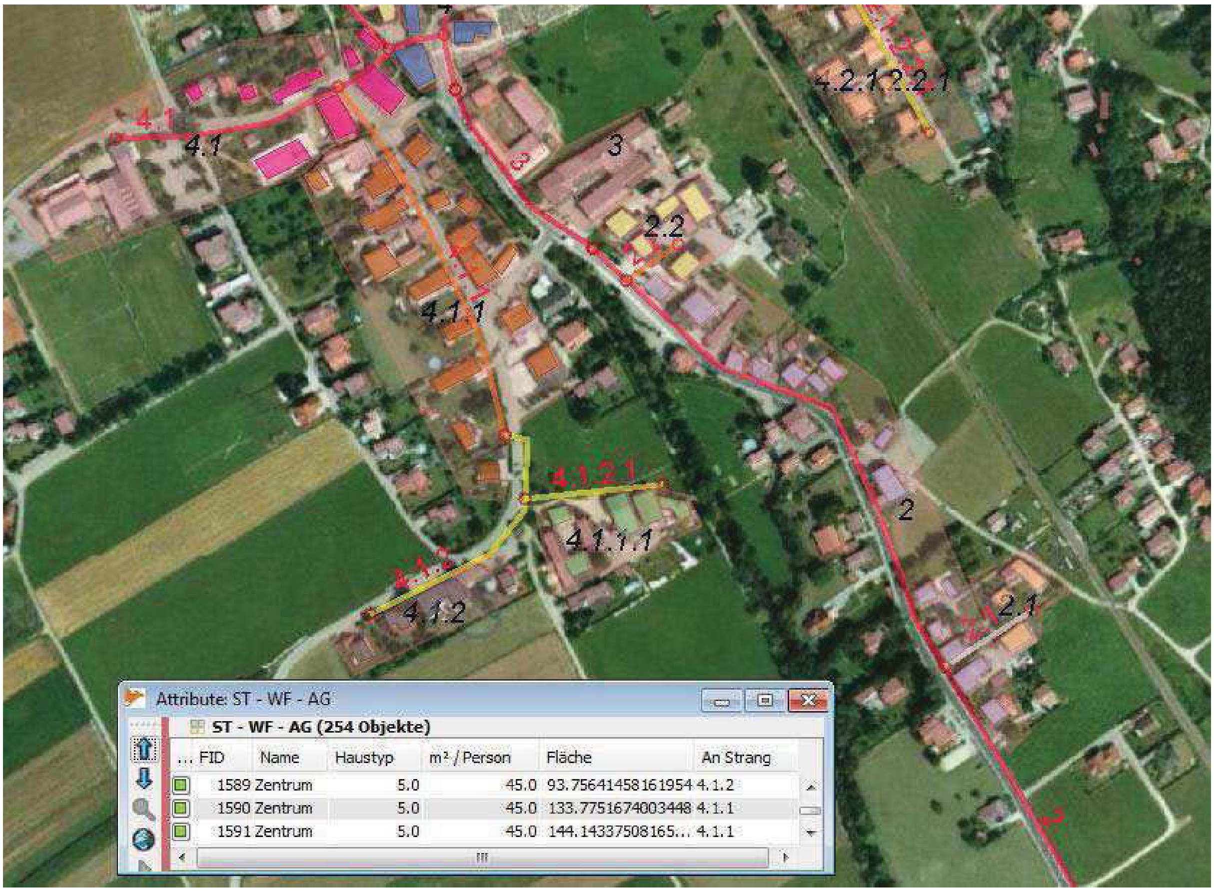
***Figure 39**: Creating network in Open Jump [own illustration]*

Illustrated is an example of how to implement a network in the geoinformation system. Each branch requires following data input: Numeration – program recognizes branch structure, stage of construction – further defined in the evaluation spread sheet (e.g. year of construction), Type of construction – further defined in evaluation spread sheet (e.g. in green land, in streets, etc. with according investment costs)

Following data needs to be imbued:

1.) Length (calculated by the program)
2.) Number of pipe
3.) Stage of completion
4.) Type of construction
5.) Remarkable crossways (Railroad, river, etc.)

In a further step connection areas for each pipeline needs to be defined. As a rule of thumb each house that's parcel is passed by a pipeline can be added. The program copies the information on each object



... FID	Name	Haustyp	m² / Person	Fläche	An Strang
1589	Zentrum	5.0	45.0	93.75641458161954	4.1.2
1590	Zentrum	5.0	45.0	133.7751674003448	4.1.1
1591	Zentrum	5.0	45.0	144.14337508165...	4.1.1

Figure 40: *Connection areas of pipes [own illustration]*

Areas that can be connected to a certain pipe (transparent red) needs to be marked, the information on which branch number a certain object is connected to can be copied to the object attributes. Different colours of object projected areas refer to being connected to different main branches.

After the data is transferred, each costumer should contain the predefined information gained during "energy demand analysis" and information about which pipe connect it to the network.

The data than has to be stored as *ESRI file and can be exported to Excel.

8.3.1 Approximation of network costs

Network costs are governed by two main factors:

1.) Material Costs
    a. Pipe type
    b. Pipe diameter
    c. Pipe length
2.) Construction costs
    a. In green land
    b. In streets
    c. Crossways

Approximation of material costs

As pipe type and pipe length are already known, missing variable is pipe diameter, its calculation (approximation) is described in this chapter. As illustrated in Figure 41***,*** the program recognizes the logical order of pipes according to their numeration.

<u>Each pipe recognizes:</u>

1.) Group of costumers it connects (= Connection area)
    a. Amount and type of energy demand
    b. Amount and type of customers

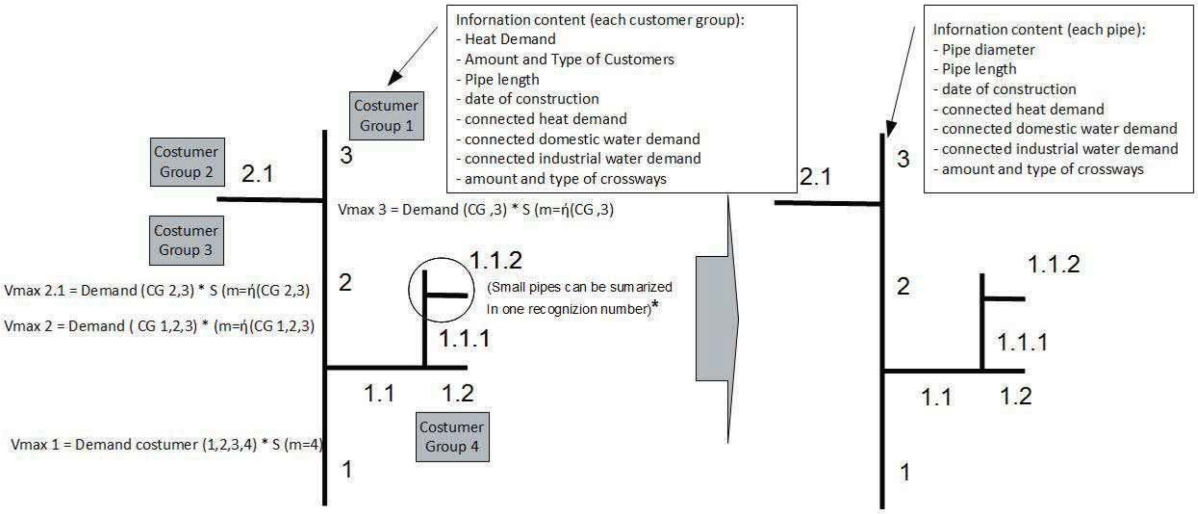


Figure 41: *Calculation of Vmax and rules of numeration [own illustration]*

Illustrated is the calculation of the maximum capable volume flow, together with the defined forward and backward flow Temperature required maximum transferable energy and necessary pipe diameter can be calculated.

V= Volume flow [m³/s], Demand= Heating or Domestic water energy [kWh], CG=Costumer Group, S = Simultaneity Factor (Heating or Domestic water), m=number of costumers, $\dot{\eta}$ *(CG2) =Amount of costumers in group 2;*

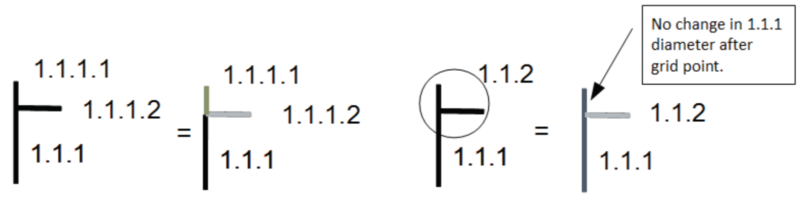


***Figure 42**: Rules for summarized branch numeration [own illustration]*

It can be time consuming to numerate every branch, for very small sub branches this is not necessary, they can be summarized as illustrated.

In a first step the required heat flow is calculated at each grid point for each energy type (heating- , domestic water-, industrial heat energy), applying simultaneity factors for smaller costumers, as described in [***Figure 41:** Calculation of Vmax and rules of numeration*](Larger costumers are not included into simultaneity calculations due to size difference, as discussed before.)

Smaller customers:

$$tHE_{(pipe)} = \sum HE_{(c.CG)} * S_{He\,\dot{\eta}(c.CG)}$$

***Equation 10:** Maximal heating energy transferred in selected pipe*

$$tDE_{(pipe)} = \sum DE_{(c.CG)} * S_{DE\,\dot{\eta}(c.CG)}$$

***Equation 11:** Maximum domestic water energy transferred in selected pipe*

Major costumers

$$tHEmc_{(pipe)} = \sum HE_{(c.CG)}$$

***Equation 12:** Total heating energy transferred in selected pipe- main costumer*

$$tDEmc_{(pipe)} = \sum DE_{(c.CG)}$$

***Equation 13:** Total domestic water energy transferred in selected pipe- main costumer*

$$tIEmc_{(pipe)} = \sum IE_{(c.CG)}$$

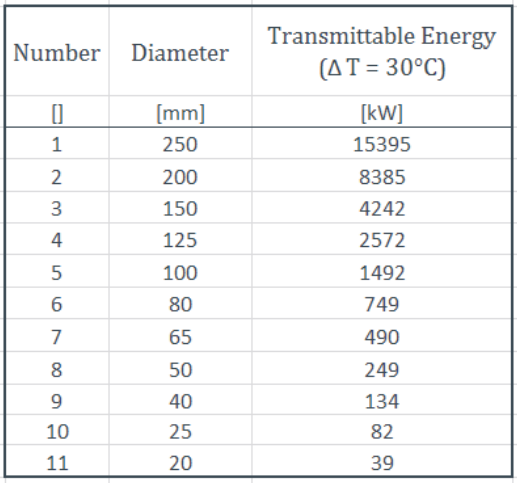
***Equation 14**: Total industrial (other) energy transferred in selected pipe- main costumer*

$$TE_{(pipe)} = \sum (tHE, tDE, tHEmc, tDEmc, tIEmc)$$

Equation 15: *Total energy transferred in selected pipe*

tHE=Total heating energy amount need to be transferred in selected pipe; DE= domestic water energy; IE= industrial (other) energy, mc = main costumer; S_{HE}*=Simultaneity factor heating energy;* S_{DE}*=Simultaneity factor domestic water energy, c.CG=concerned costumer group;*

According to the required total energy demand per pipe (including maximum volume (i.e. mass flow) forward and backward flow temperature) the program picks a fitting pipe, from a data set. See also chapter [7.3.2 Forward and backward flow temperature p. 52]



Number	Diameter	Transmittable Energy (Δ T = 30°C)
[]	[mm]	[kW]
1	250	15395
2	200	8385
3	150	4242
4	125	2572
5	100	1492
6	80	749
7	65	490
8	50	249
9	40	134
10	25	82
11	20	39

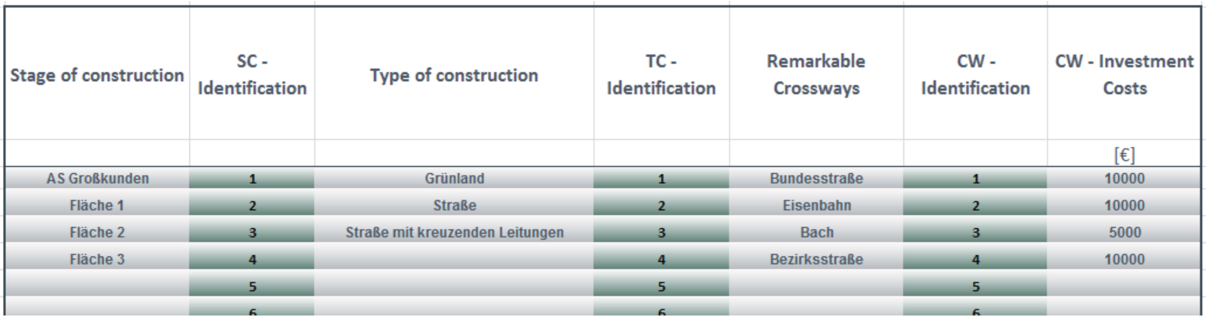
Figure 43: *Transferrable energy for various pipe diameters [according to 7]*

The data reflect the transmittable energy for plastics coated pipes at a temperature difference of 30°C. The temperature difference can be defined in “Übersicht” and will change these values in a direct proportion. If another pipe type is used values have to be exchanged.

Approximation of construction costs

In Open Jump identification numbers were introduced, they can be further defined in the evaluation spread sheet to gain an approximation for construction costs

1.) Stage of construction
2.) Type of construction
3.) Remarkable crossways



Stage of construction	SC - Identification	Type of construction	TC - Identification	Remarkable Crossways	CW - Identification	CW - Investment Costs
						[€]
AS Großkunden	1	Grünland	1	Bundesstraße	1	10000
Fläche 1	2	Straße	2	Eisenbahn	2	10000
Fläche 2	3	Straße mit kreuzenden Leitungen	3	Bach	3	5000
Fläche 3	4		4	Bezirksstraße	4	10000
	5		5		5	
	6		6		6	

Figure 44: *Definition of net branches identification numbers [own illustration]*

Stage of construction

Date of construction will be recognised. A stage of construction is defined to be constructed in one year.

Type of construction

Type of construction will influence the investment cost per m pipe.

Evaluation of total costs

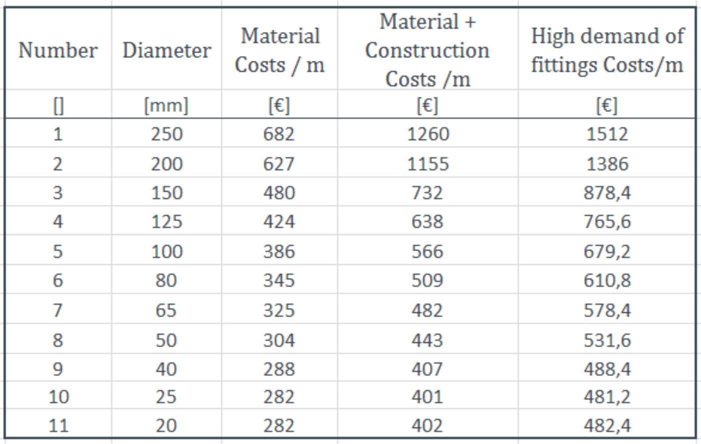
$$TC = \sum \frac{Pipecosts}{m} * l + \sum Crossways + \sum HStations + \sum Connection\ pipes + others$$

Equation 16: *Total costs*

TC = Total Network Costs; others = planning-, pump-, building-, land property costs;

$$\frac{Pipecosts}{m} = f(pipediameter, pipe\ construction\ type)$$

Equation 17: *Pipe costs per meter*



Number	Diameter	Material Costs / m	Material + Construction Costs /m	High demand of fittings Costs/m
[]	[mm]	[€]	[€]	[€]
1	250	682	1260	1512
2	200	627	1155	1386
3	150	480	732	878,4
4	125	424	638	765,6
5	100	386	566	679,2
6	80	345	509	610,8
7	65	325	482	578,4
8	50	304	443	531,6
9	40	288	407	488,4
10	25	282	401	481,2
11	20	282	402	482,4

Figure 45: *Material and construction costs for various diameters (plastic coated pipes) [own illustration according to 7]*

$$HStations = f(size, financing\ model)$$

Equation 18: *Heating stations*

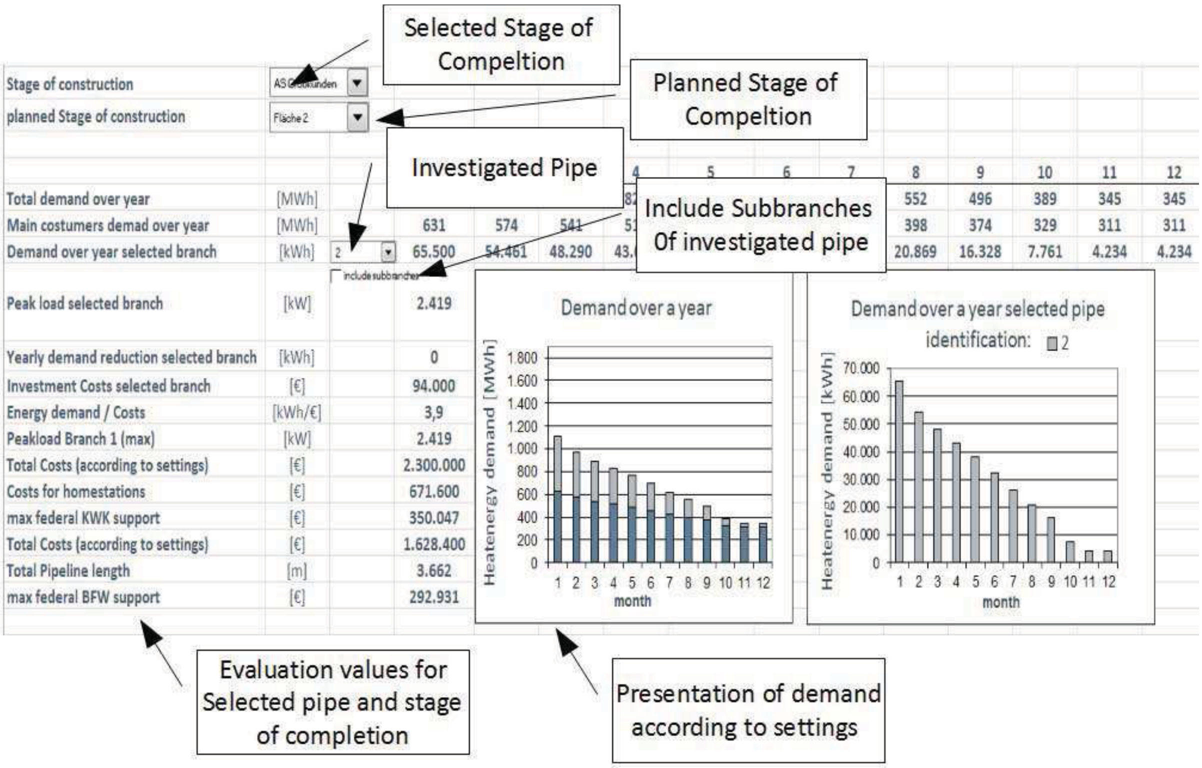
$$Crossways = f(Type)$$

Equation 19: *Crossways*

$$Connection\ length = f(average\ to\ define\ length\ and\ size)$$

Equation 20: *Connection length*

Also cost functions for buildings land property pump and planning costs are included (percentage of total costs). The total costs can be evaluated and visualised in a spread sheet



						4	5	6	7	8	9	10	11	12
Stage of construction	AS Großkunden ▾													
planned Stage of construction	Fläche 2 ▾													
Total demand over year	[MWh]					82				552	496	389	345	345
Main costumers demad over year	[MWh]		631	574	541	51				398	374	329	311	311
Demand over year selected branch	[kWh]	2 ▾	65.500	54.461	48.290	43.				20.869	16.328	7.761	4.234	4.234
		☐ include subbranches												
Peak load selected branch	[kW]		2.419											
Yearly demand reduction selected branch	[kWh]		0											
Investment Costs selected branch	[€]		94.000											
Energy demand / Costs	[kWh/€]		3,9											
Peakload Branch 1 (max)	[kW]		2.419											
Total Costs (according to settings)	[€]		2.300.000											
Costs for homestations	[€]		671.600											
max federal KWK support	[€]		350.047											
Total Costs (according to settings)	[€]		1.628.400											
Total Pipeline length	[m]		3.662											
max federal BFW support	[€]		292.931											

Figure 46: *Network evaluation spread sheet [own illustration]*

The spread sheet offers the possibility to evaluate costs of all stages of construction according to a defined final stage. In other words, visualises how the required bigger diameter for pipes, of a later stage of construction, will influence the total cost of the selected stage of construction. Economic sense, connected amount and shape of energy demand, can be evaluated quickly.

Furthermore the economic sense of single pipes (with or without sub pipes) can be evaluated by simply visualising necessary investment costs and connected energy demand (shape and amount).

This optimization should be done together with the energy supplier optimization in an iterative process.

The allocated costs are not only available sorted after stage of construction or pipeline but also temporally sorted - Yielding the cumulated costs over time.

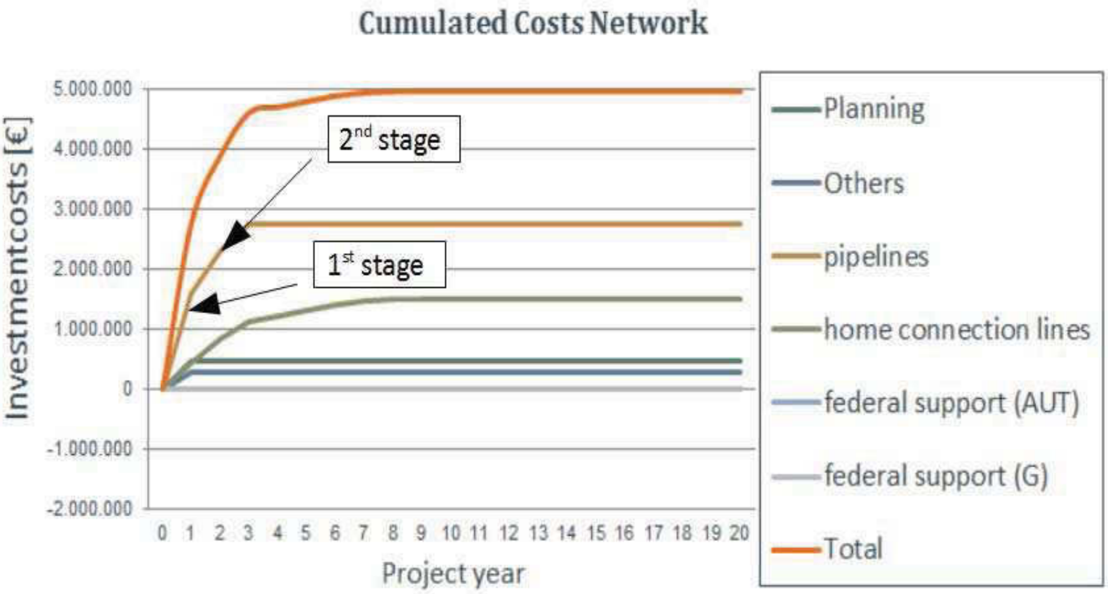


Figure 47: *Cumulated costs of network [own illustration]*

(Home connection lines include costs for home stations)

The time distribution of investment costs, are especially important in large scale project economics.

9 Evaluation software –Dynamic demand line

Information about the total demand is not enough, neither for a technical nor economical predesign. It is also required to include information about the development of the demand line during project life time

To answer following questions

1.) How to dimension the energy support?
2.) Is a module wise installation of heating energy suppliers necessary?
3.) How will the revenue delay influence the economics of the total project?

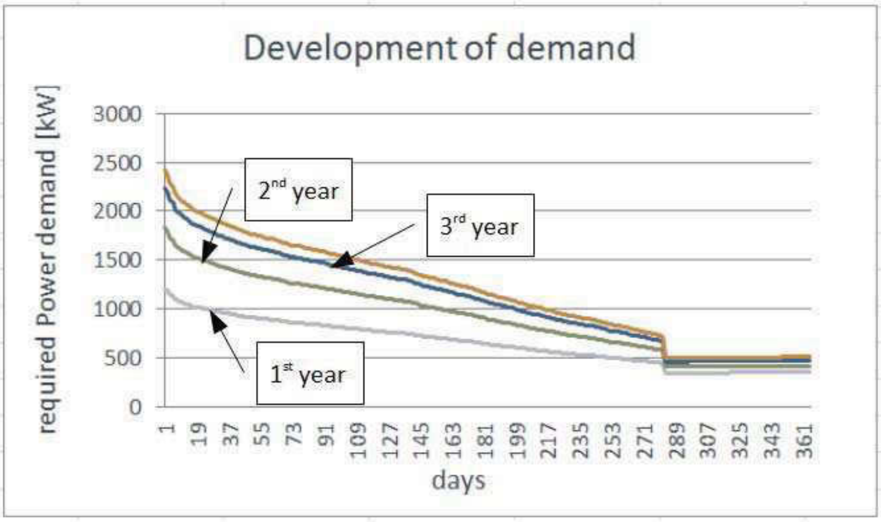


Figure 48: *Development of demand [own illustration]*

The increase of the demand line reflects network building up and costumer connecting behaviour. In this case network is built up within 3 years with relatively high starting values. From year 3 the increase is just due to costumers connecting to existing branches. Please note that the demand line does change in shape and size (!), as customers with different demand lines are connected during the project life.

It is also possible, that the demand line shrinks from one year to another .e.g. if a major costumer goes bankruptcy or energy saving measures is taken. (It is usual to calculate with a 0, 24% decrease of energy demand per year due to saving measurements and climate change)

9.1 Evaluation of software –Constructing dynamic demand line

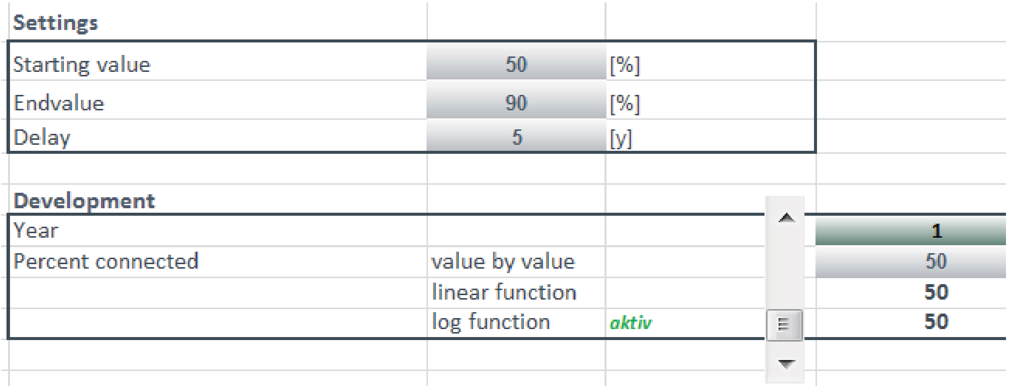
There are basically two ways to construct the dynamic demand over a year.

1.) Rough estimation mode
2.) Pre design mode

9.1.1 Rough estimation mode

For a rough estimation the following functions are provided.

1.) Linear Function
2.) Logarithmic Function
3.) Free input of values



Settings

Starting value	50	[%]
Endvalue	90	[%]
Delay	5	[y]

Development

Year			1
Percent connected	value by value		50
	linear function		50
	log function	aktiv	50

Figure 49: Input spread sheet – rough estimation dynamic demand line [own illustration]

Data is visualised according to settings in a graph.

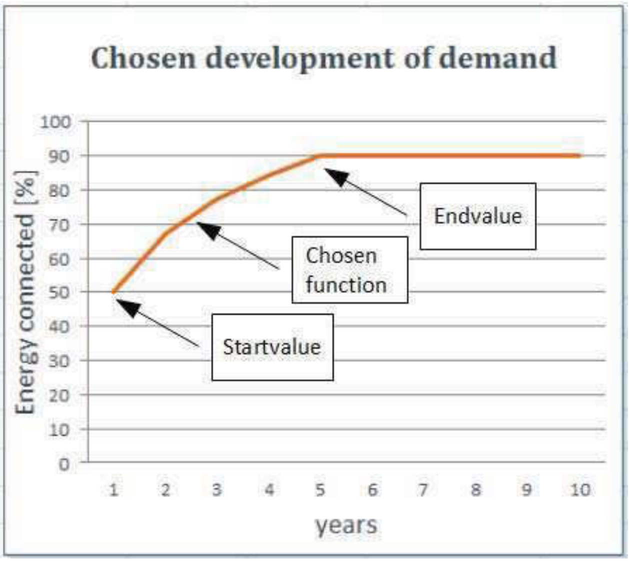
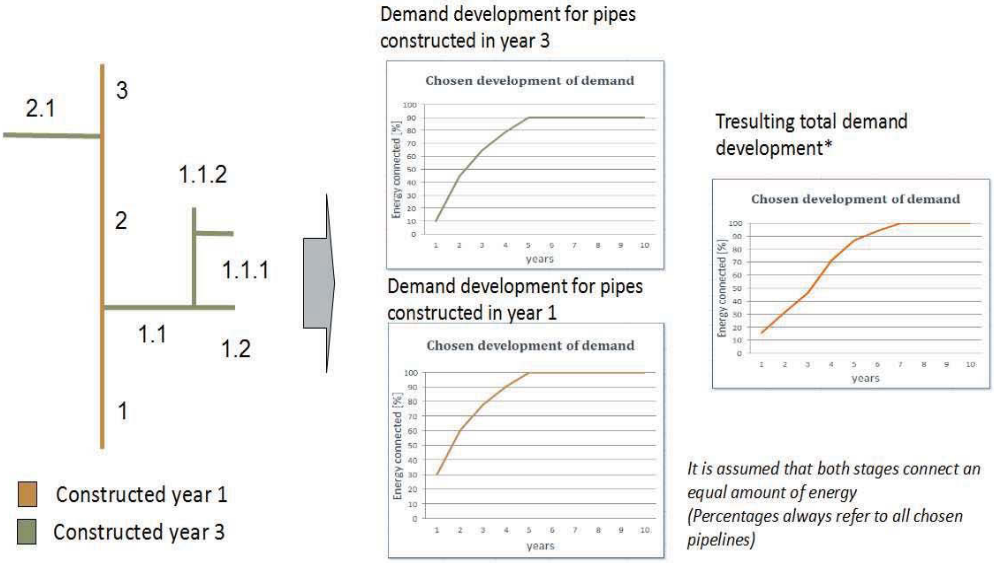


Figure 50: Visualisation of dynamic demand line [own illustration]

9.1.2 Pre design mode

For the predesign mode, Open Jump data is available - the dynamic demand of a year is constructed more complex. Date of construction for each pipe is taken into account; the delay due to connection behaviour of costumers is represented by functions (Percentage of total demand). All stages of construction are added up according to their starting years and connected customer behaviour functions. In addition the connection year of a main customer can be identified separately.



It is assumed that both stages connect an equal amount of energy (Percentages always refer to all chosen pipelines)

Figure 51: *Influence of stages of construction on dynamic demand line [own illustration]*

Illustrated is how the (due to different construction years) temporally separated customer behaviour demand development is added to the total change of absolute values of each project years demand lines

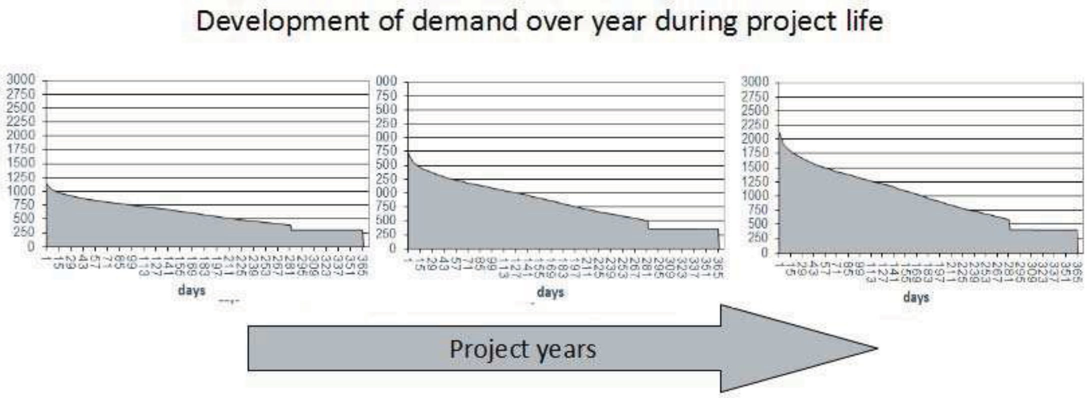


***Figure 52**: Dynamic demand line during project life [own illustration]*

The result is the dynamic demand over a year as illustrated, which is the base for the pre design of the energy concept

10 Energy concept

10.1 Predesign of energy suppliers

The area beneath the demand line represents the yearly energy demand and is split into two components

1.) Base load
2.) Peak load

From experience it is known, that the base loads portion is typically about 10 – 40 % of power and 60 – 80 % of the total required energy.

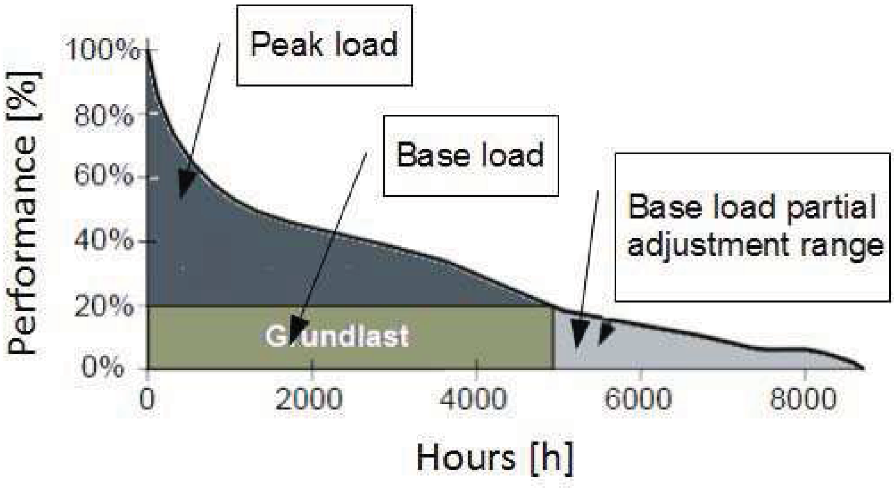


Figure 53: *Load types on demand line [modified 4]*

10.1.1 Utilization of partial adjustment range

Some base load energy suppliers cannot or only limited supply in the partial adjustment rage due to economic or technical reasons (e.g. some CHPUs (Combined heat and power unit); Geothermal wells with adapted power plant) Therefore this portion of the base load might also to be covered by peak load suppliers.

Small storage systems

Small storage systems can be used to extend the base load for not adjustable suppliers in the partial adjustment range. These storage systems should at least be able to store the energy output of half an hour to half a day, depending on the energy supplier.

Seasonal storage systems

In recent years it was tried to establish technology for large underground seasonal storage systems, which are able to store the energy overhang of the summer months for usage in winter, to cover not only the partial adjustment range, but also at least parts of the peak load by the base load supplier. These systems will be discussed in more detail later

Module wise operation

In bigger systems base load can be split in modules

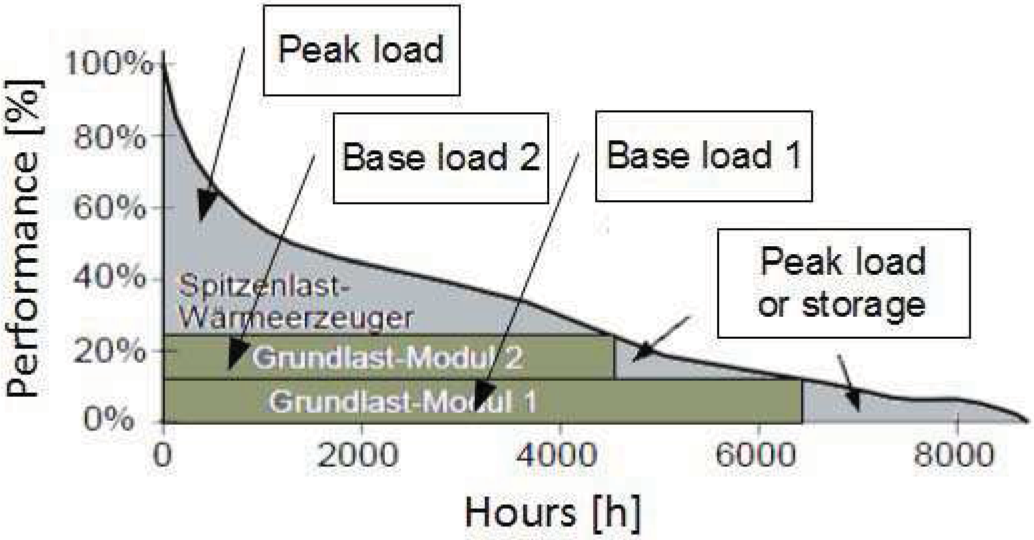


Figure 54: Module wise base load distribution [modified 4]

10.1.2 Criteria for base and peak load suppliers

In order to design and choose base and peak load providers it is necessary to consider following criteria

Base load:

1.) Operation in (near) design point
2.) High operation hours
3.) Little load changes

For base load supply capital intensive solutions with relatively high achievable internal rate of return are installed. Due to low costs per produced MWh (e.g. geothermal well, utilization of waste heat); or due to high revenues per produced MWh (e.g. CHP – additional electric power)

Peak Load

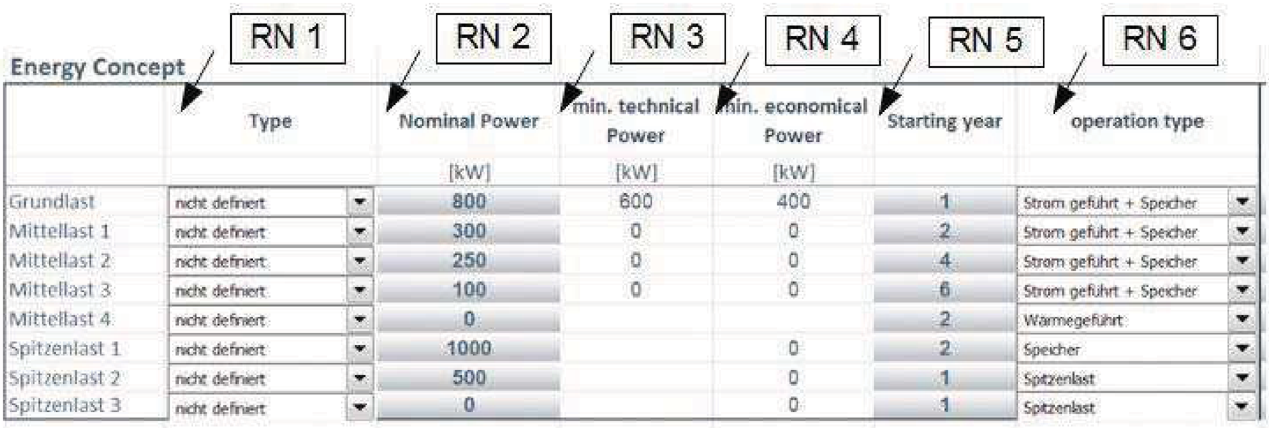
1.) Adjustable operation
2.) Low operation hours
3.) Capable of taking load changes
4.) High level of availability

Peak Load is usually covered by suppliers with low investment costs and low economic potential. (E.g. Boiler for fossil, wooden or other heating sources)

11 Evaluation software - Energy concept

As described in detail before, the dynamic demand line is the base for designing the Energy concept. This part of the software is located in the module “Overview”

11.1 Input sheet



Energy Concept

	Type	Nominal Power [kW]	min. technical Power [kW]	min. economical Power [kW]	Starting year	operation type
Grundlast	nicht definiert	800	600	400	1	Strom geführt + Speicher
Mittellast 1	nicht definiert	300	0	0	2	Strom geführt + Speicher
Mittellast 2	nicht definiert	250	0	0	4	Strom geführt + Speicher
Mittellast 3	nicht definiert	100	0	0	6	Strom geführt + Speicher
Mittellast 4	nicht definiert	0			2	Wärmegeführt
Spitzenlast 1	nicht definiert	1000		0	2	Speicher
Spitzenlast 2	nicht definiert	500		0	1	Spitzenlast
Spitzenlast 3	nicht definiert	0		0	1	Spitzenlast

Figure 55: *Input of energy concept parameters [own illustration]*

For better readability minor important settings such as ending year, and days on maintenance are not illustrated. RN = Reference number

<u>Type (RN1)</u>

Defines the type of energy supplier, following are supported by the programme in different degree of accuracy. But at least a cost and an efficiency function are provided, as suggestion. (As mentioned every output can always be overruled by the user without disturbing the program)

1.) Geothermal (hot water producing) well
2.) CHPs (BHKW)
3.) Storage systems
4.) Geothermal (heat producing) well
5.) Heating boiler (Bio heating sources)
6.) Heating boiler (Fossil heating sources)
7.) Heat pump
8.) Thermal solar panels

<u>Nominal power (RN 2)</u>

Defines the nominal (maximal) power the chosen source can supply

<u>Min technical power (RN 3)</u>

Defines in how far the chosen supplier is adjustable

<u>Min economic power (RN 4)</u>

Defines the demand at which the power source is finally switched off. In other words if a technical downward adjusting to 600 kW is possible, and min economic power is set to 400 kW – energy losses of 200 kW are accepted before being switched off.

<u>Starting year (RN 5)</u>

Year in which the energy supplier is online

<u>Operation type (RN 6)</u>

There are basically six possibilities to operate an energy supplier, which will be discussed in a own chapter

1.) Strict heating demand operation
2.) Heating demand operation
3.) Strict power demand operation
4.) Power demand operation including seasonal storage
5.) Operation as storage
6.) Operating as supporter

11.2 Operation type

11.2.1 Strict heating demand operation

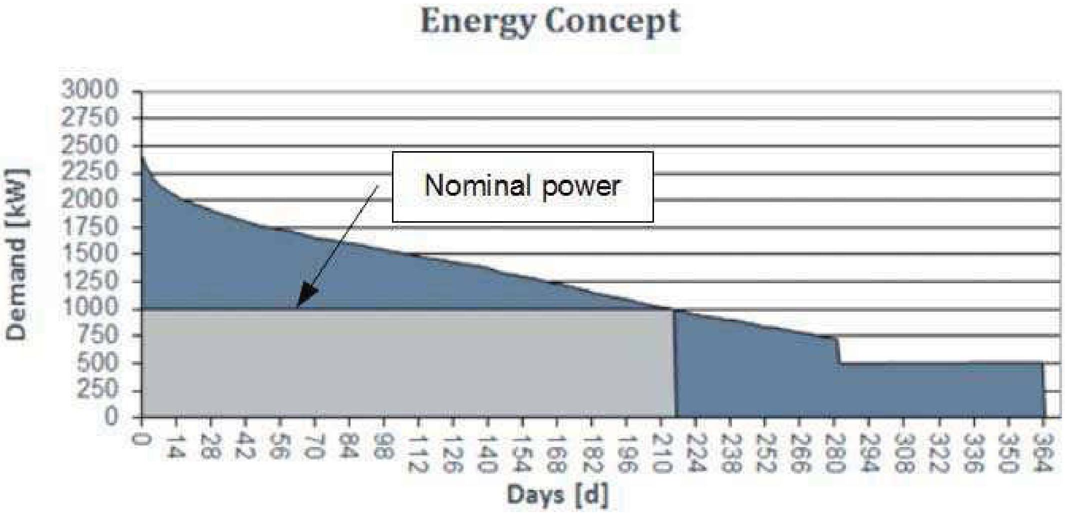


Figure 56: *Strict heating demand operation [own illustration]*

Settings: Nominal Power: 1000 [kW]

This operation type switches off exactly, if not the total nominal heat energy can be utilised, this is more or less a theoretical operation type. Even though some governmental regulations demand it for receiving federal support, it never prevailed in practice. At least a certain predefined amount of energy loss will be accepted.

11.2.2 Heating demand operation

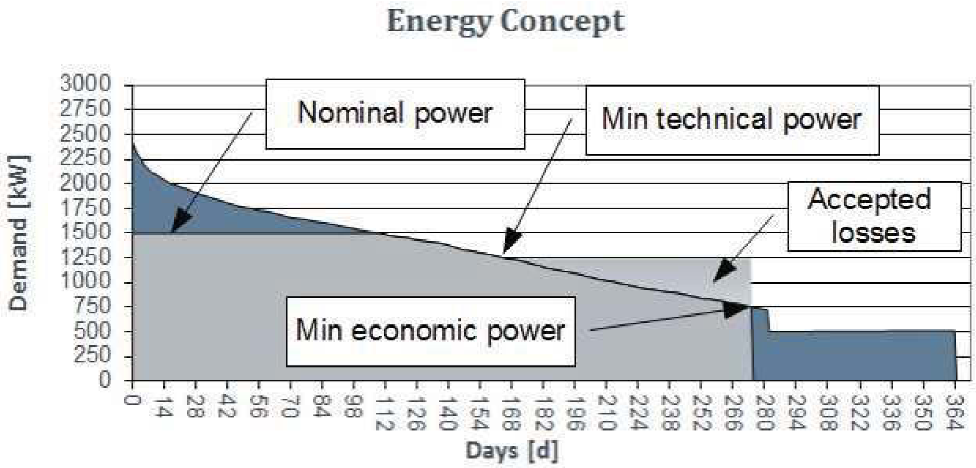


Figure 57 *Heating demand operation [own illustration]*

Settings: Nominal power: 1500 kW; Min technical adjustable power: 1250 kW; Minimum economic power 750 kW

Some heating energy sources can adjust their delivered power to some extend = part load behaviour (e.g. Geothermal well – adjustment range of pump). This can be considered with the “Minimum technical adjustable power” input. In most cases it will be accepted, that certain amount of energy is lost, which can be adjusted by “Minimum economic power”

This operation type will be used most often in practice; exact settings will be governed by federal regulations and economics.

11.2.3 Power demand operation (including seasonal storage)

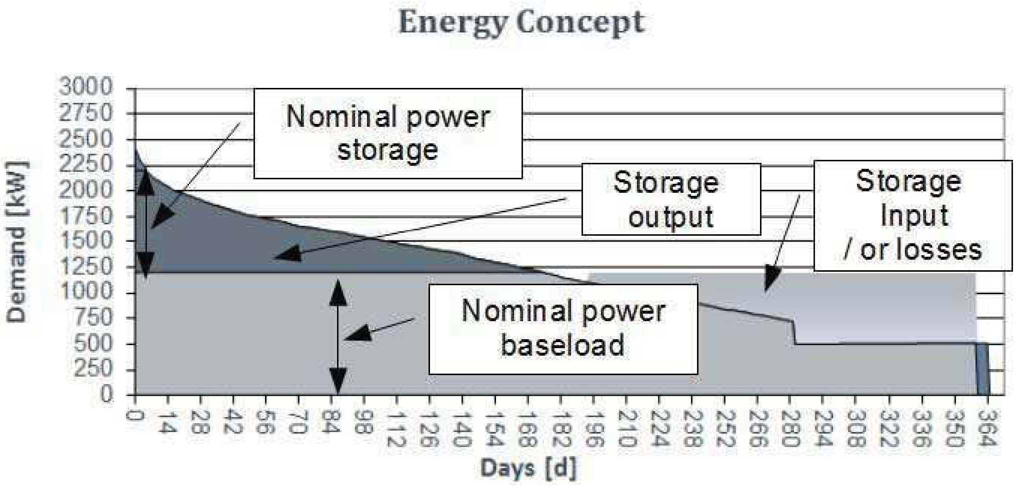


***Figure 58**: Power demand operation including seasonal storage [own illustration]*

Settings: Base load nominal power: 1200 kW; Storage nominal power: 1000 kW

This operation type is only valid for heating and electric energy producing plants. It includes two operation types:

1.) Strict Power demand operation
2.) Power demand operation including seasonal storage

11.2.4 Strict power demand operation

Strict power demand operation will always run the base load supplier on nominal power, without regarding heat demand (e.g. geothermal wells with included electric power plant).

This operation type can be chosen either by setting the storage efficiency to zero or in heat demand operation type by setting min. technical power equal to nominal power and min economic power to zero.

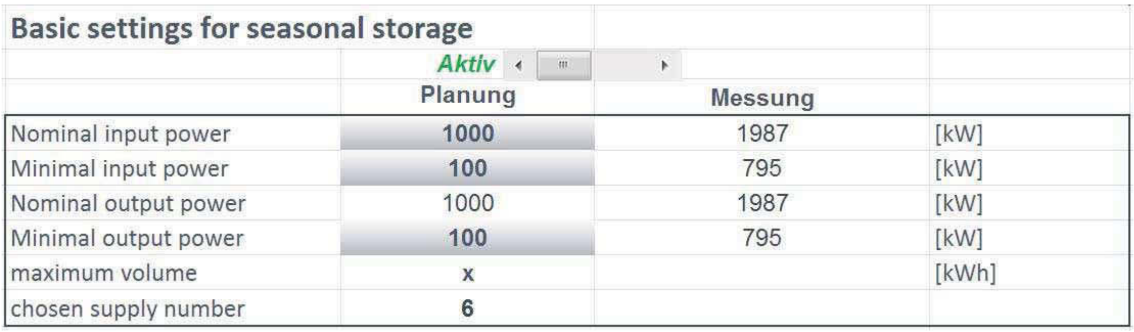
11.2.5 Strict power demand operation including seasonal storage

Base load supplier will run on nominal power throughout the year, storing the energy overhang on the low side of the demand line (summer) for the high side in the winter months.

Storage types that are capable of the required volumes will be discussed.

11.2.6 Operated as storage

At least one supplier has to be defined as storage, if one other is operated in “Strict power demand operation including seasonal storage” mode.



Basic settings for seasonal storage

Aktiv

	Planung	Messung	
Nominal input power	1000	1987	[kW]
Minimal input power	100	795	[kW]
Nominal output power	1000	1987	[kW]
Minimal output power	100	795	[kW]
maximum volume	x		[kWh]
chosen supply number	6		

Figure 59: *Basic settings for seasonal storage [own illustration]*

Input can be chosen in planning or measured mode – which is not relevant at this point. More important are the settings of nominal and minimal, input and output power which defines the operating power window for the storage system. Maximum required Volume can be calculated after predesign. Chosen supply number = Reference number in supply system as illustrated in Figure 55: Input of energy concept parameter

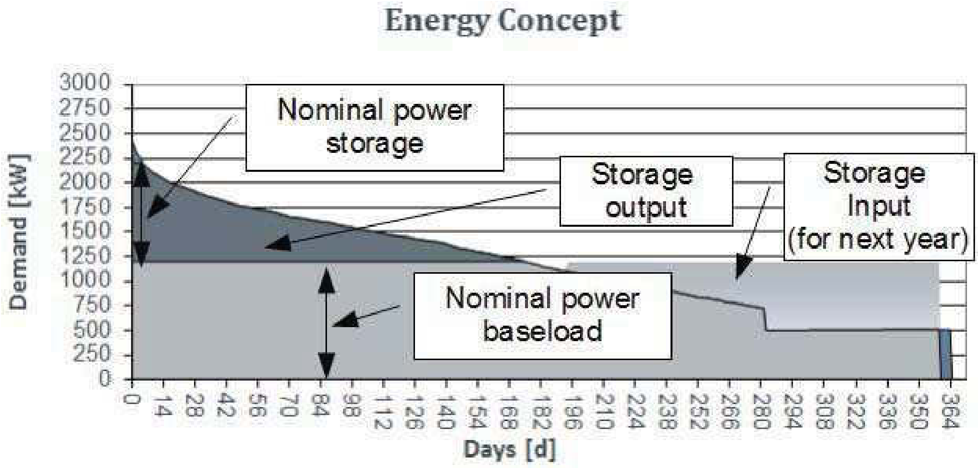


Figure 60: *Storage input vs. output [own illustration]*

As illustrated input and output are defined via the nominal base load value, in the ideal case Storage output covers the complete peak load. This can be limited by the discussed storage settings, for example reducing minimum or maximum storage power.

$$Output(t, NBL) = Input(t-1, NBL) * \acute{\eta}_{Storage}(t-1)$$

Equation 21*: Optimum storage in and output as function of nominal busload and time*

Output = Heat energy output [MWh]; Input = Heat energy input [MWh]; $\acute{\eta}_{Storage}$*= Storage efficiency []; t = Time [d]; NBL =Nominal base load*

Please note that all variables in Equation 21:are functions of time. Output and input are governed by development of demand line (see also: Figure 48: *Development of demand*) and additional energy suppliers. Storage efficiency will be discussed according to storage types, but typically a storage system needs time to “swing in”.

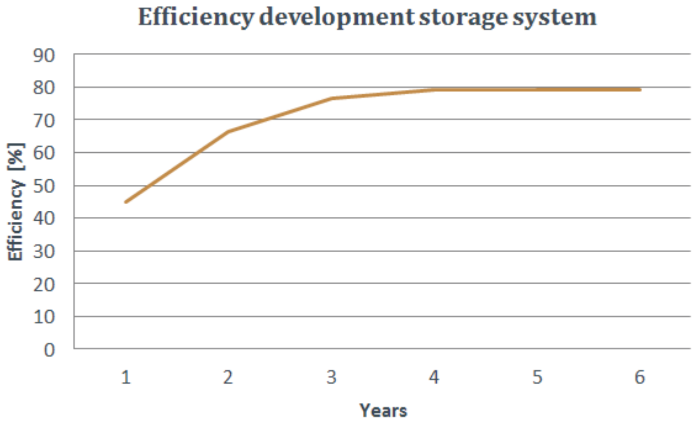


Figure 61: *Efficiency development of a storage system (assumed values) [own illustration]*

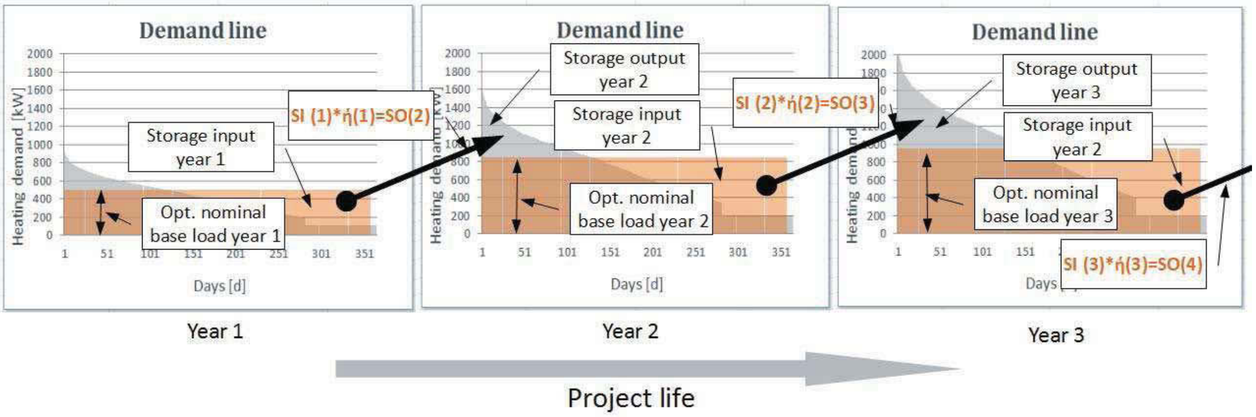


Figure 62: *Optimum nominal base load for a seasonal storage [own illustration]*

Illustrated are the first three years of a rapid developing demand line, assuming peak load is fully covered by an unlimited storage system. Point of this figure is - how the base load of one selected year influences the required storage input from the year after and the storable energy for next year’s output. In other words every change of a single year’s base load influences all other base loads. Therefore this system cannot be solved analytically. SI = Storage input [kWh]; SO = Storage output [kWh];

As illustrated in “Figure 62: *Optimum nominal base load for a seasonal storage*” and described in “Equation 21:” the ideal base load cannot be calculated analytically for a certain year, because it influences both:

1.) The required storage output - charged in the year before
2.) The required storage input – to be used in the year after

Excel offers a tool that in principal can be used to iteratively solve these kinds of problems, called “Solver”. However demand line is not calculated by a formula, but consists of 364 single values. Additionally the storage in and output, additional peak load is stored again as 364 single values each. If a multistage goal seeking would be run over the project life time this would mean approximately 75.000 calculations each iterative step (if a single base load supplier is assumed), as excel not only calculate values, but also needs to actualise concerned cells, the calculation would probably last hours or days. (Even if the input sheet would allow it)

This is the reason why, for solving the problem following procedure is used. The user inputs the first year in which he considers the changes from the year before and to the year after as negligible. (Storage system has swung in, network is completely constructed and most costumers have connected)

Valid:

$$Output(selected\ year) = Input(selected\ year) * \acute{\eta}_{Storage}(selected\ year)$$

Equation 22: *Optimum storage in and output in a static system*

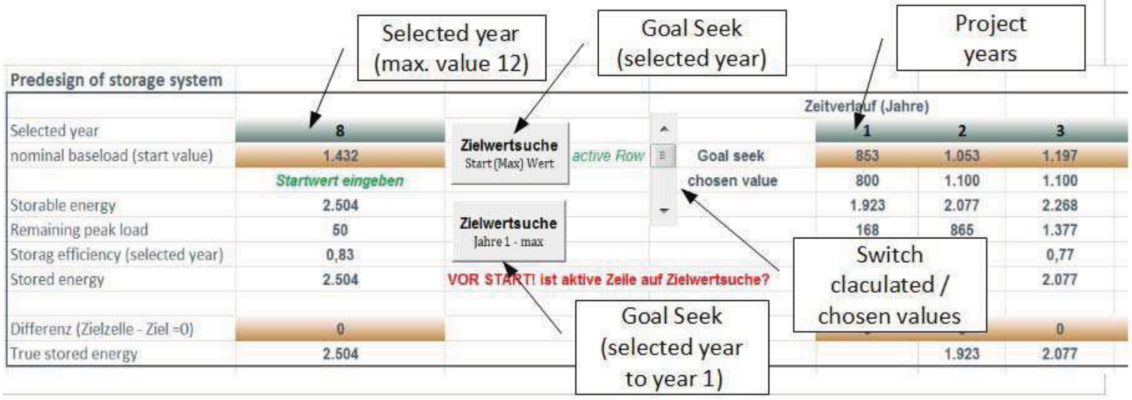
A goal seek is run in the selected year (e.g.: year 8) to find the nominal load for which Equation 22: *Optimum storage in and output in a static system* is valid. The nominal load for the year before (e.g.: year 7) is adjusted fit to the selected year (e.g.: year 8) neglecting its influence on its year before (e.g. year 6)

Valid

$$Output(selected\ year - 1) = Iput(selected\ year) * \acute{\eta}_{Storage}(selected\ year - 1)$$

Equation 23: *Optimum storage in and output in a dynamic system with a known start point*

This is done by a simple goal seek, as the input of the selected year (e.g. year 8) is fixed. The nominal base load of this year (e.g. year 7) is calculated in a way to yield a storage input that fits to the required storage output of the selected year (e.g. year 8). The resulting required storage input for this year (e.g. year 7) will be fulfilled by again adjusting (goal seek) the nominal base load of the year before (e.g. year 6). This procedure is continued until year 1 is reached.



Predesign of storage system					
			Zeitverlauf (Jahre)		
Selected year	8		1	2	3
nominal baseload (start value)	1.432	Goal seek	853	1.053	1.197
	Startwert eingeben	chosen value	800	1.100	1.100
Storable energy	2.504		1.923	2.077	2.268
Remaining peak load	50		168	865	1.377
Storag efficiency (selected year)	0,83				0,77
Stored energy	2.504				2.077
Differenz (Zielzelle - Ziel =0)	0				0
True stored energy	2.504			1.923	2.077

VOR START! ist aktive Zeile auf Zielwertsuche?

Figure 63: *Input cells "Predesign of storage"[own illustration]*

Illustrated is the input surface for the optimum nominal base load design. Procedure: 1.) Choose year with negligible changes 2.) Enter starting value and press "Goals Seek selected year" 3.) Copy the calculated base load in the line "Goal seek" and in the row of the selected project year 4.) Set the switch on "Goal Seek"5.) Press the button "Goal seek (selected year to year 1) 6.) Calculation takes a few minutes. 7.) Set the switch on "Chosen value" 8.) Choose fitting nominal base loads

This procedure yields the optimized sum of nominal base loads as illustrated in "Figure 64*: Optimized nominal base load and chosen approach*"; however in a real project the energy design can never strictly follow this suggestion. Technical applicability and other concerns will enforce a compromise –"Figure 64 (blue line)"

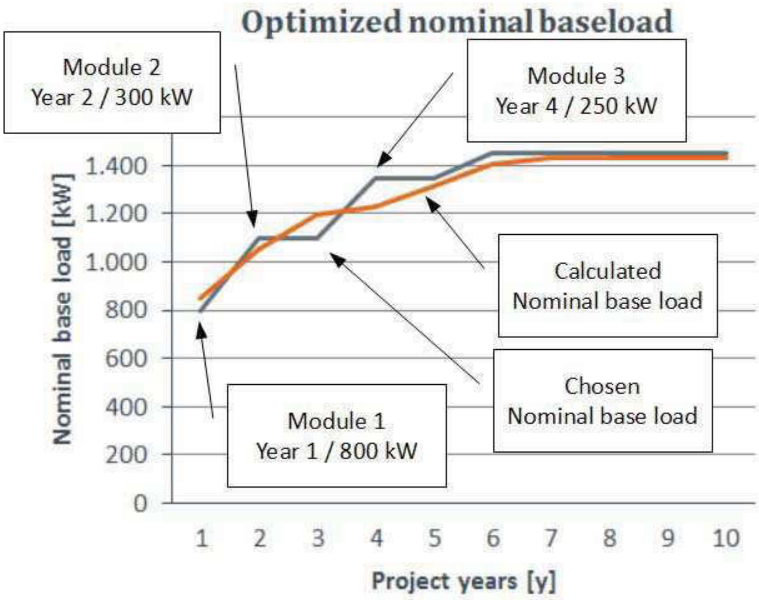


Figure 64: *Optimized nominal base load and chosen approach [own illustration]*

The resulting differences will be evened out by the program automatically adjusting the days the base load providers or the storage system is online. (As illustrated in *Figure 65*)

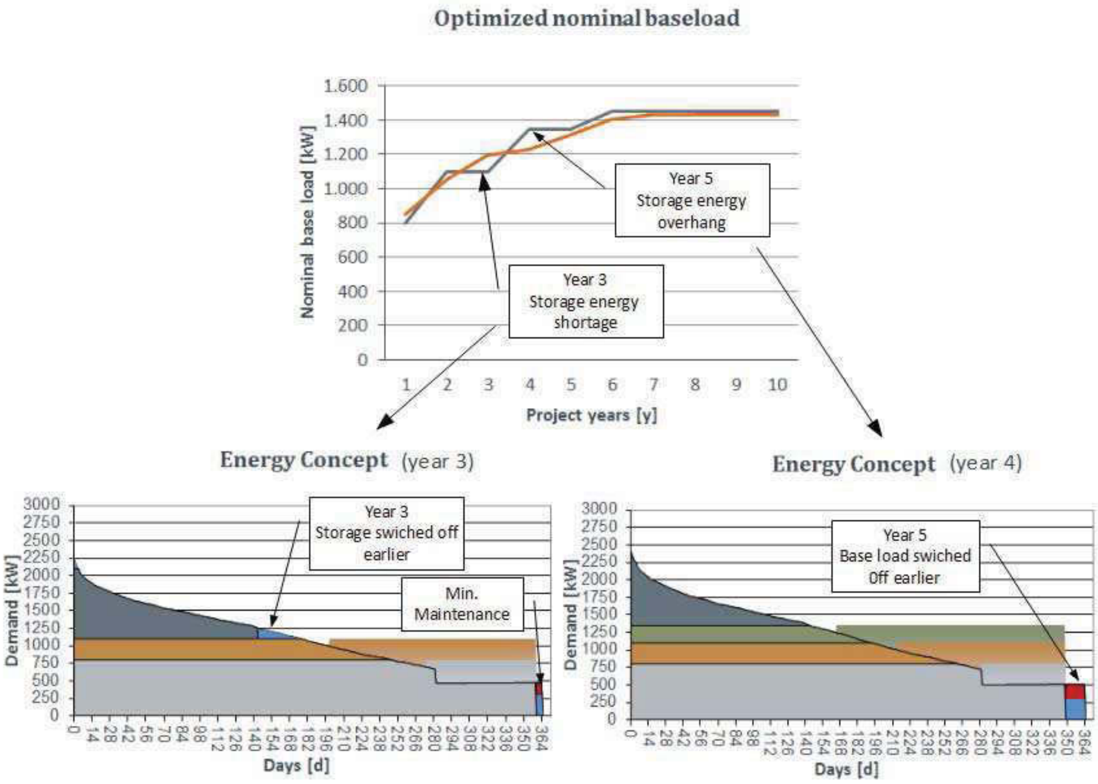


***Figure 65**: Adjustment of storage in and output by days online [own illustration]*

Illustrated is: Due to compromises in the energy concept, the ideal nominal base load is never reached. In this example it is approached with 3 energy supply modules (in the concerned years). The approach leads to energy overhang (year 5) which is avoided by switching off the base load earlier in the year before (year 4). Energy shortage (year 3) is considered by switching off the storage system earlier. These regulations are performed automatically by the program

11.2.7 Operated as peak load

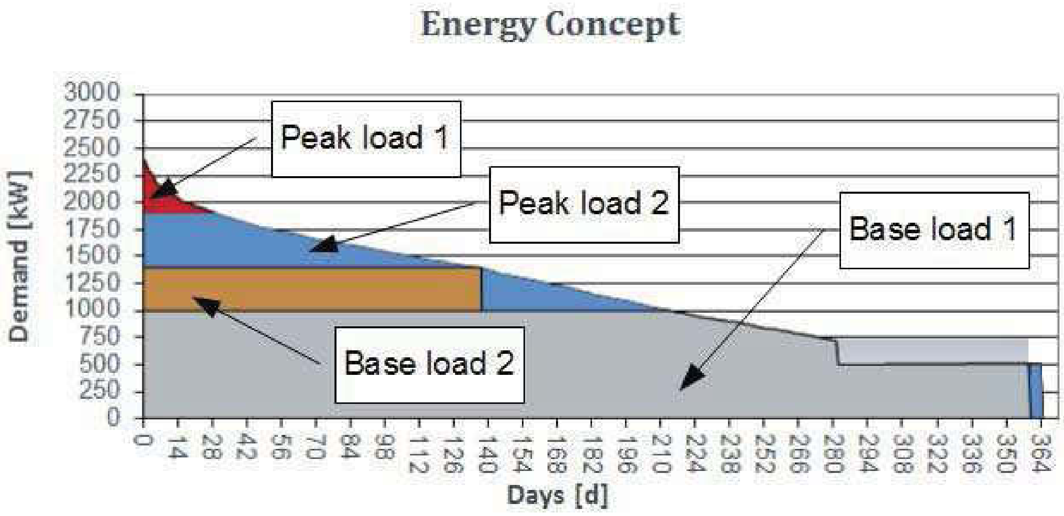


***Figure 66:** Operation as peak load [own illustration]*

Settings: Base load 1: Operation mode: “Heating demand” Nominal power: 1000 kW, Min tech. Power: 750 kW, Min eco, power: 0 kW; Base load 2: Operation mode “Strict heating demand” Nominal power: 250 kW; Peak load 1: Operation mode “Peak load” Nominal power: 500 kW; Peak load 2: Operation mode “Peak load” Nominal power: 300 kW;

An energy supplier in operation mode “Peak load” will start supplying if there is neither base load, nor preferred peak load support. A peak load support is preferred, if it is defined first in the input spread sheet.

11.2.8 Operated as support

Operating as support can be used if an energy supplier supports another because temperature needs to be levelled up.

For example a geothermal well is operated in “heating demand operation” mode providing energy for a 60 to 30 °C community heating network.

The geothermal well however is able to produce just at a level of 55°C. As support a boiler is installed, which delivers hot water at a level of 100 °C.

The program calculates the required additional energy output from the boiler to achieve the required mixing energy (direct proportion).

This is not a perfect way to address this kind of operation mode, as network temperature is not constant throughout the year. But the network operation mode and the exact required temperatures are known after a complete network simulation; therefor this attempt has to be enough for first estimations.

11.2.9 Summary energy concept

If all energy suppliers are input in the described way, the program will recognize

1.) Amount of energy supplied
    a. From which provider
    b. At which time
2.) Basic settings of energy supplier
    a. Nominal base load
    b. Adjustability

This data set is the basic for pre designing the energy suppliers and optimizing the whole project

12 Predesign of energy suppliers

Working on this thesis multiple renewable energy supply systems have been investigated, in order to find applicable combination with oil and gas technology.

It is not topic of this work to discuss all these various renewable energy supply systems; this would go far beyond the scope of this work.

A brief description is given to those energy suppliers which have made it in the final first choice of projects, this will include

1.) Geothermal wells
2.) Geothermal wells including low temperature power plants
3.) Geothermal wells including combinations with traditional thermal power plants
4.) Geothermal heat storage systems
    a. Combined with thermal solar panels
    b. Combined with biogas CHP units
    c. Combined with other CHP units than biogas
5.) Compressed air electric energy storage system*

These energy suppliers will only be discussed in view of the chosen projects size and type.

*briefly touched

13 Geothermal wells

Please note that the general part is only an overview, all necessary detail information will be discussed project specific in the evaluation software part.

13.1 Definition of subject matter

A geothermal well in this work is defined to be

1.) Water producing
2.) Production horizon: Malm
3.) Part of a large scale project, supplying a standard heat distribution network and optional a low Temperature power plant

Other geothermal wells of smaller scale, supplying single or a group of houses (e.g. in combination with a heat pump) were investigated, but not considered to be a first choice project. In fact not even the large scale projects are considered to be first choice, but as this work originates from an investigation of these, they are described nevertheless.

Geothermal wells, which utilizes the energy of an already drilled (shut down, or still producing with high water cut) oil or gas well, for costumers with low requirements of maximum temperature (e.g. green houses, fish tanks, backflow preheating of existing networks) are economically probably interesting, but were considered to have too high requirements on the location.

13.2 Geothermal Energy in general

13.2.1 Geothermal energy origination

Geothermal Energy is heat energy stored in the earth crust. Earth's geothermal energy originates from the formation of the planet, from radioactive decay of minerals, from volcanic activity, and from solar energy absorbed at the surface. The geothermal gradient, which is the difference in temperature between the core of the planet and its surface, drives a continuous conduction of thermal energy in the form of heat from the core to the surface. [8]

13.2.2 Usage of geothermal energy

This natural source of energy can be utilized for heating or producing electricity.

In areas of active volcanism like in New Zealand or Iceland this energy source can be developed by relatively shallow wells. In the Molasse basin the geothermal gradient is on average just about 3 °C per 100 m TVD, resulting theoretically in wells deeper than 2000 m for pure unsupported (in terms of levelling up Temperature by second heat sources) heating energy projects, and deeper than 3000 m- 4000 m for electric power and heating energy production.

13.2.3 Geological description of the Molasse basin

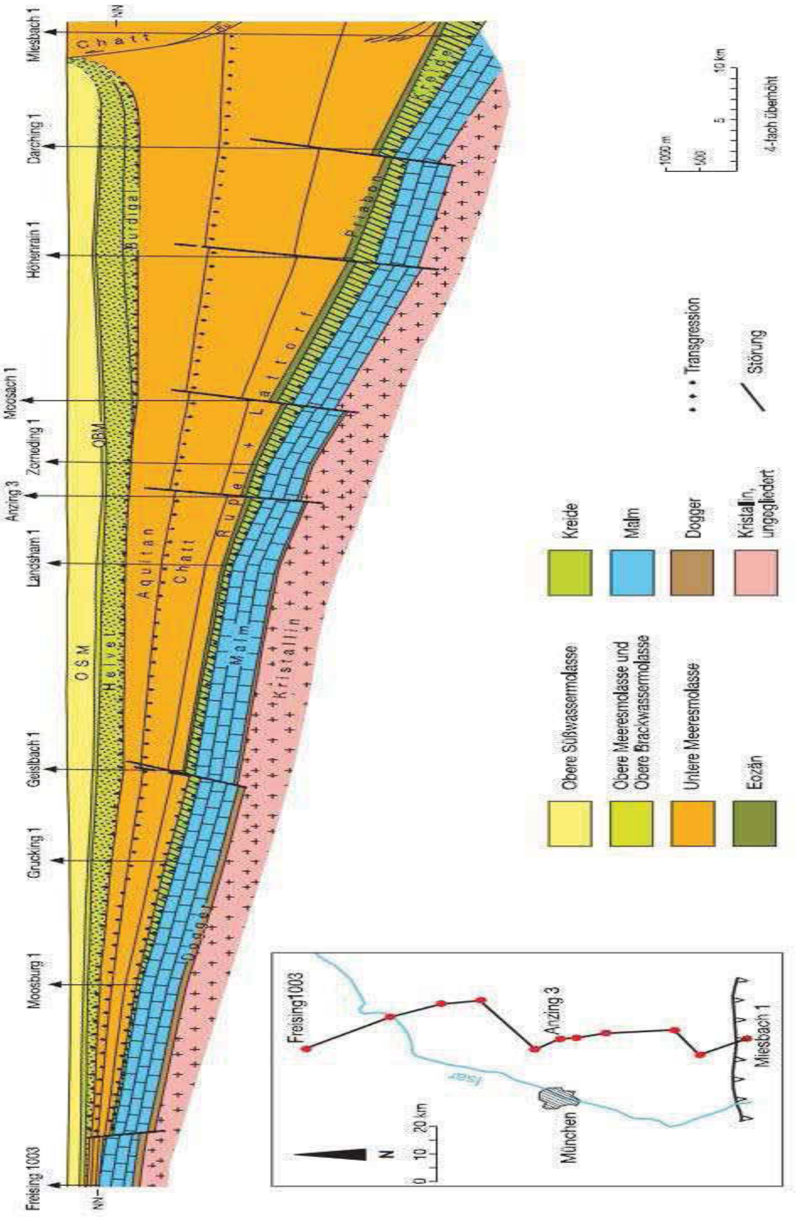
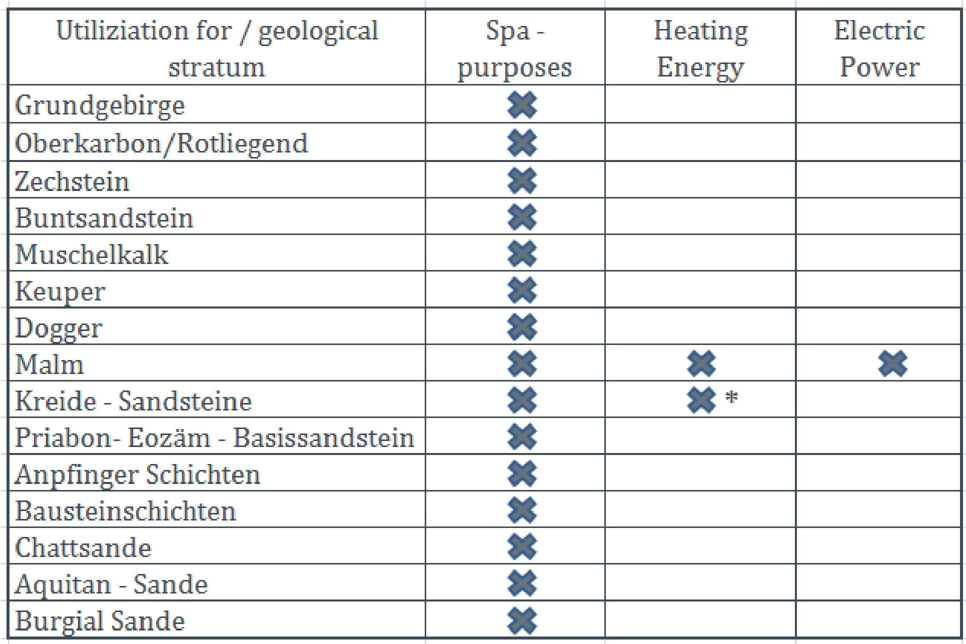


Figure 67: *Geological profile between Freising and Miesbach (Bavaria) [8]*



Utiliziation for / geological stratum	Spa - purposes	Heating Energy	Electric Power
Grundgebirge	✖		
Oberkarbon/Rotliegend	✖		
Zechstein	✖		
Buntsandstein	✖		
Muschelkalk	✖		
Keuper	✖		
Dogger	✖		
Malm	✖	✖	✖
Kreide - Sandsteine	✖	✖ *	
Priabon- Eozäm - Basissandstein	✖		
Anpfinger Schichten	✖		
Bausteinschichten	✖		
Chattsande	✖		
Aquitan - Sande	✖		
Burgial Sande	✖		

Figure 68: *Summary - Hydrothermal potential Bavaria [according to 8]*

** . limited*

Only the geological sequence “Malm” offers high enough temperatures and more important also high enough achievable production rates, for the project types that will be described in this work. Therefor the geological description will focus on the “Malm”[8]

Lithology

The Malm’s lithology is containing chalk, dolomite and clay. Chalk and dolomite will react with brittle behaviour on movements, and form typical (nearly) vertical cracks. [8]

Geological sequence description

The Malm thickness is in the area of Munich about 600 m, reducing in eastern direction to about 100 m in the area of the “Braunauer Trog” (For hydrothermal production it is very unlikely that the whole thickness can be utilized, as normally only the karst area near top of Malm offers an economic permeability). As can be seen in the North South profile the Malm has a depth of approximately 1000 - 1500 m in the North sloping down until it reaches a depth of approximately 4500 – 6000 m at the border of the Alps. [8]

Reservoir properties

As usual for the lithology the reservoirs possesses the typical low pore porosity, and gains high permeability due to cracks.

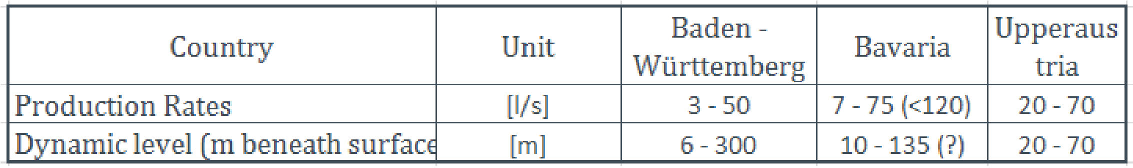
Additionally the upper Malm part was karstifyied resulting in excellent permeability and a total secondary porosity of about 2 – 2, 5 %.

Permeability values of 10^-6 to 10^-3 m/s (25 to 6000 [mD]) can be expected tending to reduce with increasing depth, however with extreme local variation.

Transmissibility values are very variable but in a range of 5*10^-5 to 5*10^-2 [m²/sec] [8]

Hydraulic description

The production rates of geothermal wells in the Malm are between 3 and 75 l/s in single cases also clearly above 120 l/s if suiting casings are provided, resulting in a dynamic pumping level between 10 and 300 m beneath surface[8]



Country	Unit	Baden - Württemberg	Bavaria	Upperaustria
Production Rates	[l/s]	3 - 50	7 - 75 (<120)	20 - 70
Dynamic level (m beneath surface	[m]	6 - 300	10 - 135 (?)	20 - 70

***Figure 69**: Production rate and dynamic level range in the Molasse basin [according to 8]*

Newer Projects (2010) such as for example Unterraching near Munich report production rates of 120 l/s, others such as Kirchschlag and Dürrnhaar are pre designed for production rates of more than 150 l/s.

The Malm water is normally under hydrostatic; the static level may be up to 300 m beneath surface. In the south of the “Braunaer Trog” Malm water is connected to other geological sequences and under slight artesian pressure. The water originates from percolating ground waters and Danube water. Flow velocities are not more than a few meters per year. [8]

Most Malm water can be classified as sweet water with local salt containing exceptions, especially in deeper areas. [8]

13.2.4 Is geothermal energy renewable?

In literature geothermal energy is considered as “renewable” energy source, which is not perfectly true in my opinion. The geothermal heat flow in the Molasse basin is about 60 to 80 mW/m² (10^-3 Watt/m²)

An average geothermal well, that serves as a heat source for an electric power plant and a heating network will produce about 10 – 70 MW and more (heat energy). The following example shall visualise the order of magnitude: The reservoir would need to have a theoretical extension of about 1000 km² to balance the production. Or in other words, the energy transmitted through the area of a soccer field would be enough to light a few (5 or 6) electric bulbs, if it could be transformed with 100 % efficiency to electric power (Real net geothermal electricity production efficiencies in the Molasse basin are normally below 5 %).

If geothermal energy can be considered renewable, has to be judged individually

Shallow wells take the main part of their energy from adsorbed solar energy, according to latest studies only a portion of 16 % originates directly from the earth heat flow. It is unsettled if this application will be influenced on the long term sight by slow cooling down of concerned area. However the influence will be relatively low.

In deep wells the adsorbed surface energy play no role, the energy needs to be recharged by the earth heat flow itself or by hot water flow systems.

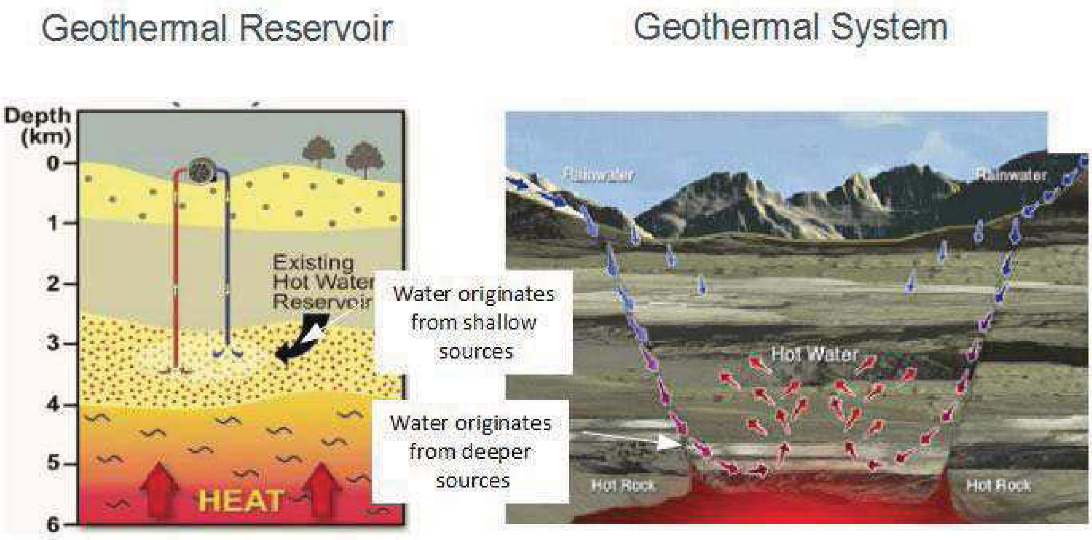


Figure 70: *Illustration of geothermal system and reservoir [unknown source]*

If the well produces a strong geothermal system, chances are good that energy will be replaced and the source can be recognised as endless or renewable by human standards. Unfortunately strong geothermal systems are unlikely in the Molasse basin, most Upper Austrian Malm water originates from surface water percolation in the Danube area flowing to south, within the Malm or shallower formations, not being heated up in deeper areas. Under some circumstances the Malm may be connected to deeper sediment reservoirs, resulting in higher temperatures than expected, and a higher productiveness. However, most likely being far apart from a renewable or endless energy source, especially if very high production rates are demanded like in recently (2010) planned projects.

Most projects claim, that they will be able to produce the reservoir for 40 years. Future will reveal, if this will become true in all cases. In a worst case scenario the production and injection well communicate immediate through an unexpected fracture. (Not meant as pressure reactions due to hydraulic communication, but direct communication of water due to high permeable flow path short cuts) Additionally we know from chalk reservoirs in other parts of the world, that the produced temperature, (which is already very low for electric power production usage), will decrease slowly, the applied power plant technology reacts sensitive to temperature changes, concerning its efficiency.

If a geothermal reservoir is produced, we must be aware of the fact, that hot geothermal water is an ending resource, which is by human standards not renewable.

A produced reservoir is likely to take several centuries to recharge its heat content.

Most deep geothermal large scale projects in the Molasse basin are not a renewable energy source.

13.3 Utilization of geothermal energy for large scale projects

13.3.1 Set up

The Molasse basin reservoirs consist of water of low enthalpy, resulting in high required production rates (50 - 120 [l/s]) to achieve necessary energy output. In order to keep the water balance in the reservoir, the produced water has to be reinjected (technical and governmental requirement), resulting in projects consisting of at least 2 wells, which have to have a minimum distance to avoid early communication.(However the risk can never be avoided completely)

The water is produced with an ESP (Electric Submersible Pump) known from oil and gas applications, the reinjection is performed by surface pumps.

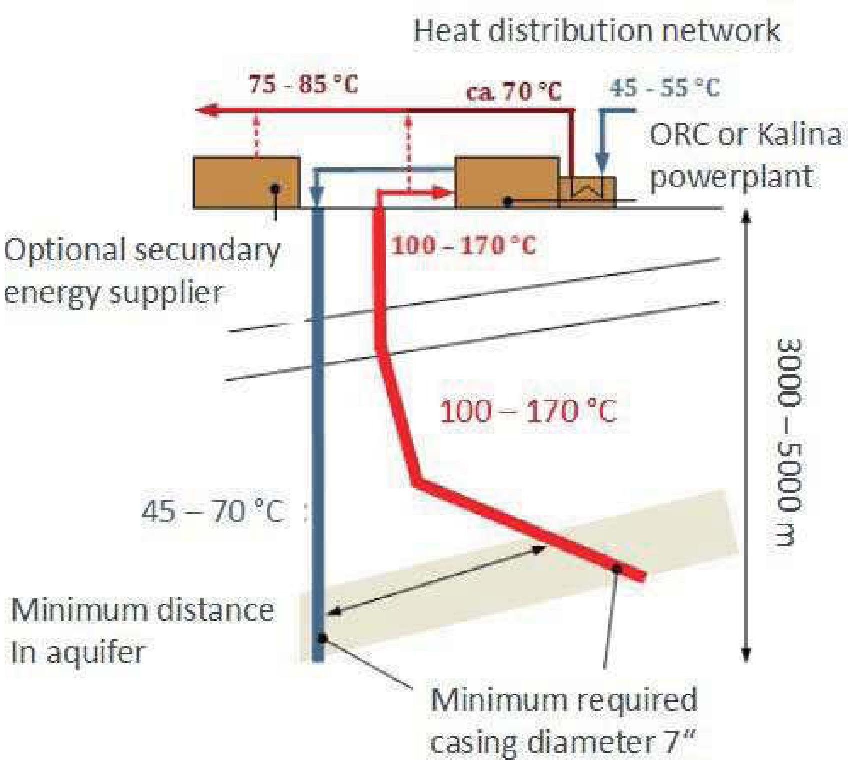


Figure 71: *Typical set up of an electric power producing geothermal project in Molasse basin [own illustration]*

Components: 1 -2 High deviated producing wells (end diameter 7” - 8 5/8”), 1 straight or low deviated injection well (end diameter 7” - 8 5/8”), a low temperature power plant (Organic Rankine Cycle or Kalina), a heat distribution network including secondary heat sources.

In case of a geothermal well without attached electricity production the energy is directly transferred to the heating network without power plant. As discussed a Temperature of 85 °C for standard costumers is necessary at least. Electricity production is technical possible above 100°C.

Typically the producing well is deviated to guarantee the well will hit the target (almost vertical) cracks, to increase the contact area of the reservoir (to increase maximum possible production) and for utilizing one drilling location for two wells (to save costs). Of course it is also possible to deviate both wells, or none of them, but preferred is the illustrated set up.

13.4 Drilling technology

Geothermal state of the art technology is basically that of oil and gas drilling, incorporating engineering solutions for problems, that are associated with high temperatures, and in case of Middle Europe also relatively high pressure due to required depths.

13.4.1 Drilling recommendations for a typical geothermal well in the area

The following (chapter 16.4.1 and sub titles) is a summary of an assumed well design done by the company ITAG [9], to address the technical challenges drilling a geothermal well in the area, in a presentation given to RAG. The author's comments are marked: "a.c.:"

General conditions

1.)	Depth:	<5000 m TVD
2.)	Completion:	Predrilled liner >7"
3.)	Production rates:	> 70 – 150 l/s
4.)	Temperature:	90 – 160 °C
5.)	Production casing:	> 11 ¾"

<u>Assuming conditions as described following setup would be possible</u>

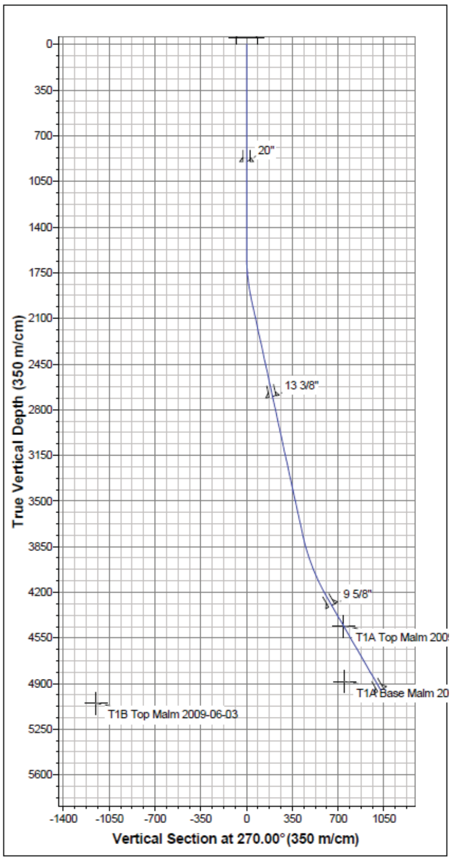


***Figure 72**: Vertical section of a possible production well design [9]*

The deviation allows higher contact area to the reservoir and assures that the typical nearly vertical target cracks will be hit. Additionally it allows the usage of one drilling location for two wells.

Surface section

Drilling:

TVD:	approx. 900 m
Bit Size:	26” (alternative 23”) (3 bits per 1000m are usually torn apart)
Achievable ROP:	3 – 5 m/h
Drill pipe:	5 ½”
Pump rates:	< 5000 l/s

Usage of “Shock Subs”

Clay based mud with high viscosity, preventing top hole losses (1, 05 – 1, 1 kg/l)

Logging

Calliper Log

Casing

Lead Cement quality G or “Visco Lead”
Support bottom flange, due to high weight of following casings

Comment

A.c.: Stinger Cementation is the worst case load scenario! It is the general trend to plan for especially large and deep surface casings, to bring down high production casing diameters. Additionally especially huge (not yet developed) pumps shall be able to set down as deep as possible.

The normally applied software Well Cat does not include Stinger Cementation as a predefined load scenario. Most often Surface Casings are therefore designed to withstand full or partial evacuation (depending on company policies and regulations)

However it might easily be that the stinger cementation load case is by far worse than even the full evacuation one. Additionally large casing diameters have a low resistance against collapsing. Design for these wells should take the load case “Stinger Cementation” into account at an early stage.

Intermediate 1 section

Drilling

TVD: approx. 2700 m
Bit size: 17 ½ (an. 16”) (PDC Bits useable until approximately 1900 m)
Achievable ROP 3 to 6 m/h
Drill pipe: 5 ½”
Pump rates: < 3500 l/s
Mud System: KCa based (~1, 15 kg/l)
Usage of Shock Subs

Expected Problems:

Loss of circulation
Differential pipe sticking

Logging

Calipper – GR / CBL

Casing

BTC Connections
Cementing to the surface
Pre tension casings with approximately 180 to
Possibly reduction of Cement weight is necessary (stage cementation or light weight cement)

Intermediate section 2 (critical section)

Drilling

TVD: approx. 4300 m
Bit size: 12 ¼” (PDC bit types)
Achievable ROP: 1 – 2 m/s
Drill pipes: 5 ½”
Mud System: KK or “Ultradrill” (up to 2, 0 kg/l)
Clay stones below the Gault formation should be cased off in this section

Logging

Calliper & GR / CBL & USIT measurement

Casing

9 5/8” Liner (alternative 11 ¾)
Cement Class G and thermal H

Expected problems

High pressured formations
Under pressured formations
Very high torque peaks, up to 50000 Nm
Mud temperature might become critical, usage of mud coolers.
Abrasive sands (Gault formation)
Total mud losses possible (A.c.: Total mud losses might be accepted on purpose due to very high recycling costs)
Loss of total section is possible

Comment

A.c.: Cementing this section from bottom to top is dictating the nominal load of the drilling rig. A 350 to net hook load rig might easily not be enough, as cementing is usually classified to be a normal load, not an exceptional load. Even though, it is sometimes demanded by rig providers.

A.c.: Due to borehole instability and mud losses, it was suggested from experienced engineers to abstain from performing time consuming logging this section, and rather case off fast.

Production section (5000 m)

TVD**:**	approx. 5000 m
Bit size:	8 ½”
Achievable ROP	5 – 8 m/h
Mud system:	$CaCO_3$ based mud (1, 1 kg/l) or pure water

Logging

Extensive Logging program
Additional seismic measurements

Casing

Predrilled 7” Liner

Expected problems

High mud losses
High torque
Small amounts of H_2S possible

Comments

Circulation of “High Viscous Pills” to assist borehole cleaning
Long term rock stability unsure
Formation is PDC applicable in principal, if high losses occur, a roller cone bit is recommended, because PDC bits don’t withstand vibrations.

Summary of known problems occurring on a regular basis

Casing collapse occurred, especially in intermediate sections, possibly due to annular pressure build up. (In the geological formations: Bändermergel, Rupel,)

Net casing wear of < 10 % of net thickness

Long term duration of casing strings during anticipated production unsure

13.5 Material and instrumentation problems due to temperature

1.) Change of mud properties – loss of circulation
2.) Thermal effects on casing strings
3.) Effects on logging and MWD tools.
4.) Effects on seals

13.5.1 Change of mud properties – Loss of circulation

During drilling a well the loss of fluid is normal and necessary, the fluid carries mud particles in the rocks surrounding and to the borehole wall surface, building the internal and external filter cake. Providing borehole stabilisation and prevents further loss of drilling mud

Lost circulation means that the whole mud system (fluid and plugging particles) are lost to the formation, resulting in a mud level drop within the borehole. This problem can cause loss of primary borehole control; as well the cuttings suspended in the drilling mud may fall back in the annulus clogging the drill pipe.

Additionally in case of loss of circulation, new drilling fluid must be mixed and pumped fast enough to sustain flow and keep the bit clean, which can be an expensive process. Loss of circulation appears especially in high permeable reservoirs and preferred if the permeability arises due to cracks, like in the Malm. High fluid temperatures also decrease the viscosity of the drilling mud, further increasing the risk of lost circulation.

Fluid flow from the hole into the loss zone may also remove cement, preventing completion of a sheath around the casing from the shoe to the surface, or from the shoe to the liner hanger.

In most published reports (in the area), drilling companies mention complete mud loss at top of Malm and in the Malm itself. This is physically hard to believe, as even though the Malm is slightly under hydrostatic, pressure balance should be reached after the mud column has fallen 100 to 200 [m] at maximum.

My personal suspicion is, that drilling companies just pump at the end of a section before required change of mud system on purpose, as long as all high performance mud is gone, to safe recycling cost, which are especially in Bavaria extremely high (approximately 300 €/m³)

In oil and gas technology lost circulation problems have been reduced somewhat by the use of light weight fluids such as foams and air. Leading to underbalance drilling technology, where the well fluids are allowed to constantly influx in the well, which results in decreasing the chip hold down effect and therefore allows higher rate of penetration. Disadvantage is the unknown fluid composition within the wellbore and the danger of drilling without primary well control.

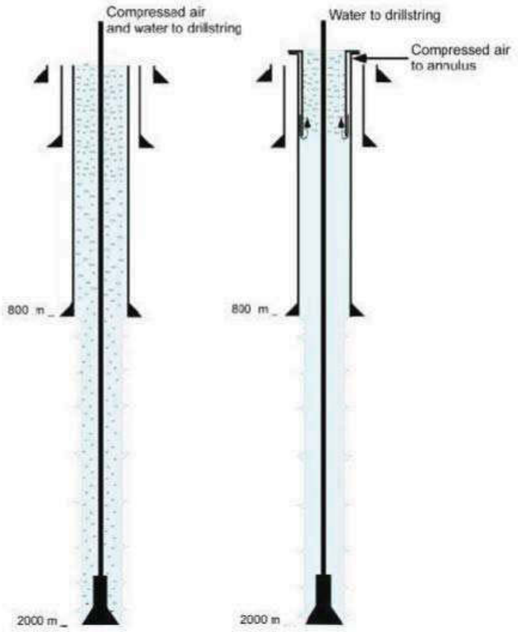


Figure 73: *Illustration of two technologies to lighten up the mud weight with air [9]*

Cementing problems can be reduced by lightweight cement or foam cement. Selection of appropriate cement is critical, because a failed cement job is extremely difficult to fix.

Drilling fluids / "Mud" coolers.

Surface "mud coolers" are commonly used to reduce the temperature of the drilling fluid before it is pumped back down the hole. Regulations usually require that mud coolers be used whenever the return temperature exceeds 75°C (170°F), because the high temperature of the mud is a burn hazard to rig personnel. The drilling fluid temperature at the bottom of the well will always be higher than the temperature of the fluid returning to the surface through the annulus, because it is partly cooled on its way upward by the fluid in the drill pipe. High drilling fluid temperatures in the well can cause drilling delays after a bit change. "Staging" back into the well may be required to prevent bringing fluid to the surface that may be above its boiling temperature under atmospheric conditions. [10]

13.5.2 Thermal effects on casing

Reduction of yield strength

Steels temperature has an effect on the materials properties, especially yield strength and ductility of material. Cold temperatures would increase brittle material behaviour while hot temperatures decreases the yield strength

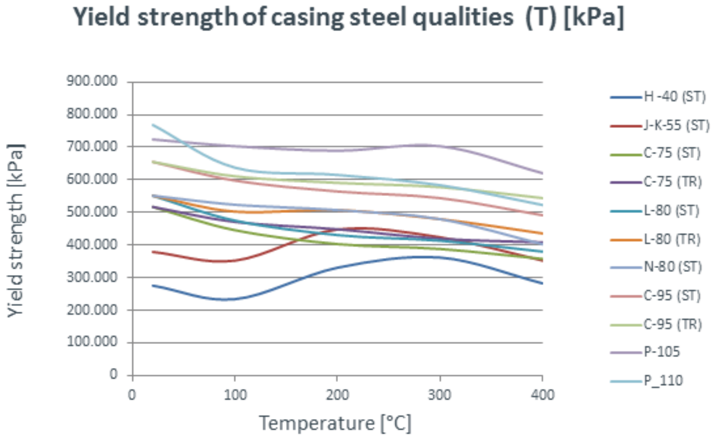


Figure 74: *Yield strength of casing steel qualities as a function of temperature [unknown source]*

Interesting is, that temperature yield strength deration is different throughout the steel qualities. Especially the lower qualities like J-K 55 offer even better yield strength at 200 °C than the C75 and L 80 (TR) qualities. Considerable are also the losses of the best steel quality P110 even at relatively low Temperature levels

In casing design programmes such as “Well Cat” or “Stress Check” it is usual to calculate with an average temperature deration per °C (2 %/°C).

Thermal expansion

Thermal expansion can cause buckling and casing collapse (“moon shaped deformation”). Also thermal contraction due to cooling in injection wells, or thermal cycling can lead to damage and possible tensile failure of casing,

It is recommended to cement all casing strings from the shoe to the surface to provide support and stability against thermal movements. Additionally the base (within the meaning of: base opposite to acid) cement acts as a shield against corrosion. In typical oil and gas wells in the region this is not necessary, oil and gas liners are often only tagged at the bottom with a cement column of 100 to 300 m of cement, to isolate zones. [10]

Problems of thermal movement of casing can be handled with confidence by using full sheath cementing and surface expansion spools, especially at Temperatures clearly below 250 °C as in the Molasse basin (Hottest well “Dürnhaar”: (expected) 175 °C)

Loss in yield strength and resulting necessary design is covered by applying sophisticated software. [10]

13.5.3 Effects on instrumentation

As easy developable oil reserves are running shorter and shorter, the industry is forced to develop also hard accessible reserves. One of these reserves is so called “Ultra deep”. Wells of more than 8000 m are drilled to explore and produce them, exposing instrumentation to high temperature. [10]

High temperature problems are most frequently associated with logging and directional drilling equipment. Until recently, electronics have had temperature limitations of about 150°C. Heat shielded instruments, which have been in use successfully for a number of years, are used to protect down hole instrumentation for a period of time. However, even when heat shields are used, internal temperatures will continue to increase until the threshold for operation of the electronic components is breached. Batteries are affected in a similar manner when used in electronic instruments. Recent success with “bare” high temperature electronics has been very promising, but more improvements are needed. [10]

13.5.4 Directional drilling

Directionally drilled wells reach out in different directions and permit production from multiple zones that cover a greater portion of the resource and intersect more fractures through a single casing. An electricity producing geothermal power plant typically requires more than one well. In terms of the plant design, and to reduce the overall plant "footprint," it is preferable to have the wellheads close to each other. Directional drilling permits this while allowing production well bottom spacing's of more than 900 m. [10]

The tools and technology of directional drilling were developed by the oil and gas industry and adapted for geothermal use. Since the 1960s, the ability to directionally drill to a target has improved immensely but still contains some inherent limitations and risks for geothermal applications. In the 1970s, directional equipment was not well-suited to the high temperature down hole environment. High temperatures, especially during air drilling, caused problems with directional steering tools and mud motors, both of which were new to oil and gas directional drilling. However, multilateral completions using directional drilling are now common practice for both oil and gas and geothermal applications. The development of a positive displacement down hole motor, combined with a real-time steering tool, allowed targets to be reached with more confidence and less risk and cost than ever before. Technology for re-entering the individual laterals for stimulation, repair, and work overs is now in place. Directional tools, steering tools, and measurement while drilling tools have been improved for use at higher temperatures and are in everyday use in geothermal drilling; however, there are still some limitations on temperatures. [10]

13.5.5 Logging tools

The use of well logs is an important diagnostic tool that is not yet fully developed in the geothermal industry. For oil and gas drilling, electric logging provides a great deal of information about the formation, even before field testing. Logs that identify key formation characteristics other than temperature, flow, and fractures are not widely used for geothermal resources. Geothermal logging units require wire lines that can withstand much higher temperatures than those encountered in everyday oil and gas applications. [10]

13.5.6 Effects on seals

Fluid temperatures in excess of 190°C may damage components such as seals and elastomeric insulators. Bit bearing seals, cable insulations, surface well control equipment, and sealing elements are some of the items that must be designed and manufactured with these temperatures in mind. Elastomeric seals are very common in the tools and fixtures that are exposed to the down hole temperatures. [10]

13.6 Drilling technologies with cost saving potential

Theoretically there are various possible attempts to reduce drilling costs for geothermal wells in the Molasse basin.

However, to come to the point, in my opinion it is very optimistic to assume this projects overall economics could be solved by applying new drilling technology. This is because large geothermal projects, most likely will not have a high enough potential in future, due to several reasons.

The author doubts, that the very limited number of possible projects will allow to climb down the learn curve for applying really new technologies, nor will economically allow necessary investments. The only possibility that will probably make modest sense is, trying to optimize well path and casing schema in order to save costs and spare pump energy. Nevertheless a short summary of technologies with theoretical potential to save well costs is given:

13.6.1 Expandable tubular casing

Casing and cementing costs are high for deep wells due to the number of casing strings and the volume of cement required. A commercial available alternative is to use expandable tubular to line the well. Further development and testing is still needed to ensure the reliability of expandable tubular casing in wells where significant thermal expansion is expected. [10]

13.6.2 Under reamers

Monobore designs that use expandable tubular require under reamers. The use of under reamers is common in oil and gas drilling through sediments, and provides cementing clearance for casing strings that would not otherwise be available. However, high qualities under reamers for hard rock environments are not common, with expansion arms often being subject to failure. [10]

13.6.3 Low clearance casing design

An alternative approach to using expandable tubular is to accept reduced clearances. A well design using larger casing and less clearance between casing strings may be appropriate. Although closer tolerances may cause problems with cementing operations, this can usually be remedied by the use of under reamers before cementing. [1]

13.6.4 Drilling with casing

Is an emerging technology that has the potential to reduce cost. This approach may permit longer casing intervals, meaning fewer strings – and, therefore, reduced costs. Research is needed to improve our understanding of cementing practices that apply to the drilling with casing technique. As with expandable tubular, the development of reliable under reamers is key to the advancement of this technology. [10]

13.6.5 Multilateral completions /stimulating through side tracks and laterals

Tremendous progress has been made in multilateral drilling and completions during the past 10 years. However, pressure based stimulation of reservoirs may still prove difficult, unless the most sophisticated (Class 5 and Class 6) completion branch connections are used. The successful development of reliable re-entry schemes and innovative ways to sequentially stimulate reservoir development sets may be necessary, if the additional cost of such sophisticated completion practices is to be avoided. [10]

13.6.6 Well design variations

Considerable savings are possible if the length of casing intervals is extended. This will reduce the number of casing strings, and therefore, the diameter of the surface and first intermediate casings. The success of this approach depends on the ability to maintain wellbore stability of the drilled interval and to install a good cement sheath. There may be isolated intervals where this technique will be appropriate.

13.7 Geothermal electric power plant technology

13.7.1 Clausius Rankine Cycle

Thermo dynamic processes are described in model cycles, such as for example the Carnot Cycle or the Otto motor cycle etc.

In geothermal electric power plant technology, the heat is used to create steam of high enthalpies of a pressured liquid media; the steam is decompressed and cooled down in a turbine, further cooled down in a condenser to liquefy the media again.

The theoretic thermodynamic cycle used is the Clausius Rankine Cycle

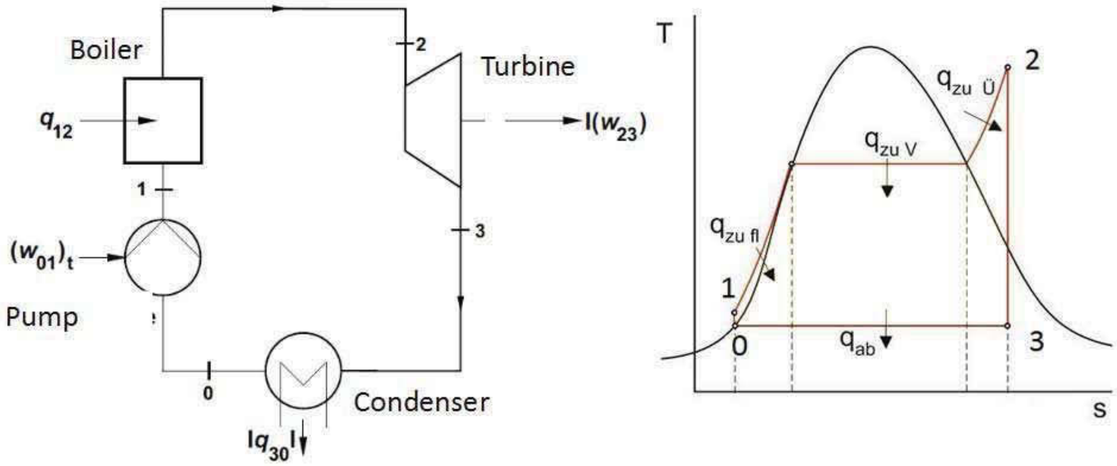


Figure 75: *Clausius Rankine Cycle (CRC) [modified 11]*

0 -> 1 Liquid carrying media is pressurised by the pump (Isentropic increase of pressure)

1 -> 2 Heating up (isobar) of carrying media ($q_{zu\ fl}$. heating up to boiling point; $q_{zu\ V}$ vaporisation of liquid media; $q_{zu\ Ü}$ further heating up of vapour (super heating)

2 -> 3 adiabatic uncompressing in the turbine

3 ->0 Isobaric condensation

13.7.2 Clausius Rankine Cycle efficiency and furnace bulk temperature

$$\acute{\eta}_{cr} = \frac{h(2) - h(3) - [h(1) - h(0)]}{h(2) - h(1)}$$

***Equation 24**: Clausius Rankine Cycle efficiency [11]*

h = Enthalpies [J]

h (2) – h (3)… work performed in the turbine

h (2) – h (1) … required heating energy

h (1)-h (0) … work done in the feeding pump, about 0, 5 of total work

The efficiency can therefor also be written as

$$\acute{\eta}_{cr} = \frac{w(23) - w(01)]}{q(12)} = 1 - \frac{q30}{q12} \triangleq 1 - \frac{To}{Tm,12}$$

***Equation 25:** CRC efficiency and furnace bulk temperature [11]*

w= useable work [J]; heating energy [J]; Tm, 12 = furnace bulk temperature [K], to = low cycle side temperature [K], q (30) heating energy from the process (in condenser) q (12) heating energy in the process (boiler)

W (01) ~ 0

As can be seen in Equation 24 and Equation 25, the efficiency is dependent on two temperatures, the low cycle side temperature and the furnace bulk temperature. In a peanut the furnace bulk temperature is a number, which describes the usable amount of Energy (Exergy) in a Thermodynamic process.

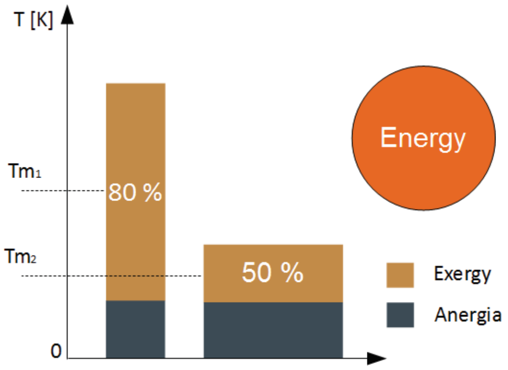


***Figure 76**: Illustration of furnace bulk temperature [own illustration]*

Illustrated is the same amount of energy on different temperature levels, represented by the furnace bulk temperature. This temperature defines the amount of energy that is usable in thermodynamic processes; this is why it has a major impact on the total efficiency

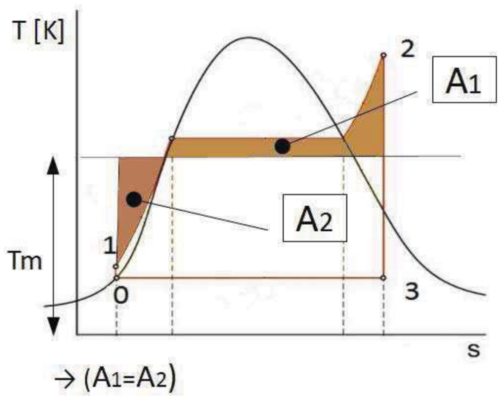


Figure 77: *Furnace bulk temperature in the CRC (T – S diagram) [modified 11]*

Graphically the furnace bulk temperature can be shown as the temperature in which both areas (1, 2) are equal

Please also note that the work done by the heat carrying media is represented in the area of the cycle represented in the T – S Diagram.

13.7.3 Possible improvements of the Clausius Rankine process

To improve the efficiency of the process, it is necessary to increase the furnace bulk temperature as discussed. It would also be theoretically possible to reduce to however this is limited to a maximum allowable liquid percentage in the turbine

Increasing of boiler temperature

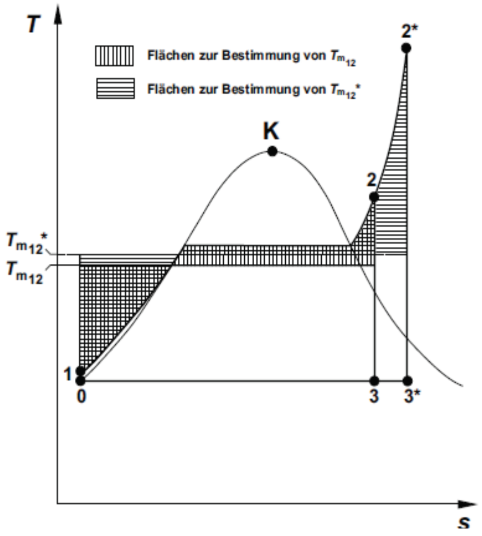


Figure 78: *Effect of increasing T2 (boiler temperature) on efficiency [11]*

Even a very large increase of the boiler temperature results only in a slight improvement of Tm, this is due to the increasing steepness of the isobars. [11]

Additionally this attempt is limited due to material properties, normal standard fossil power plants heat up the media (water) up to 450 – 550 °C. Special steel might withstand also Temperatures of up to 600°C (in future possibly 700 °C), resulting in little improvement of the overall efficiency [according to 11]

Increasing pressure

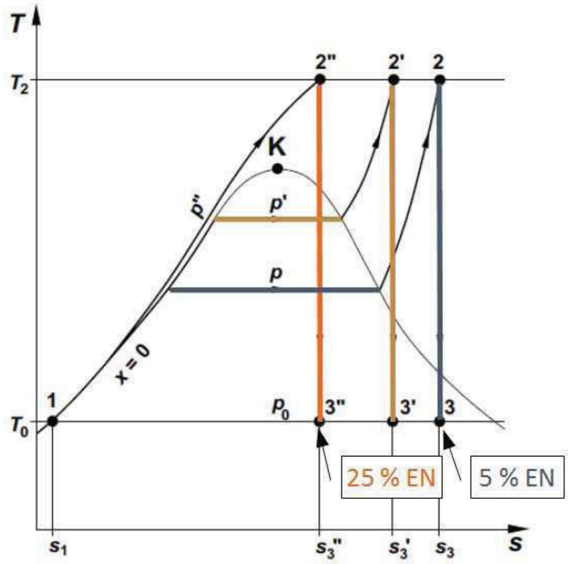


Figure 79: Effect of increased pressure on Tm [modified 11]

(p”>p’>p), EN = water percentage in vapour (in turbine ~ 5 % allowed)

Pressure increase is resulting in a higher Tm, on the other hand however it is limited due to maximum allowable water content within the turbine. (Usually 5 %) Normal pressure ratings in modern fossil power plants are about 250 bars and more. [11]

Reheating

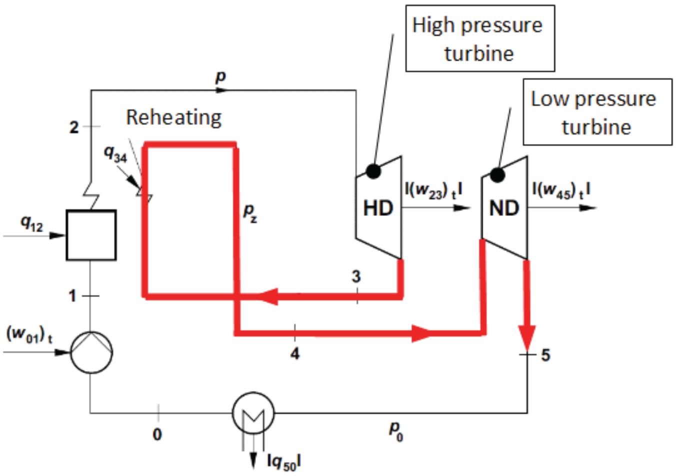


Figure 80: Schematic of a CRC including reheating [modified 11]

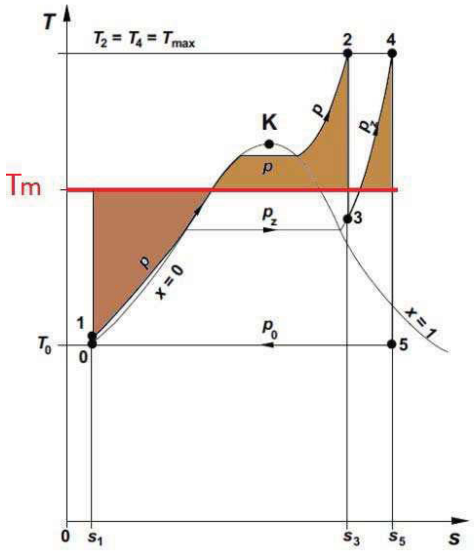


Figure 81: CRC including reheating in a T – S diagram [modified 11]

As illustrated in the T – S diagram the preheating combines both concepts (higher pressure and more heating energy are imbued). Due to the vapour being reheated after the high pressure turbine, additional heating energy can be fed to the process, without requiring higher boiler temperatures. Another benefit is that the high pressure in the first turbine does not yield to damaging water contents, as pressure is reduced and vapour reheated before finally cooled down in the second low pressure turbine.

Feed water preheating

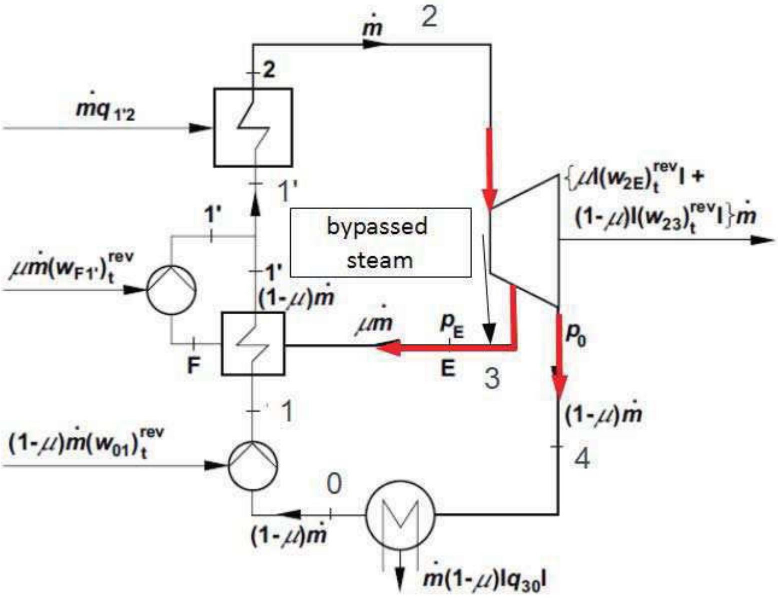


Figure 82: Schematic of CRC including feed water preheating [modified 11]

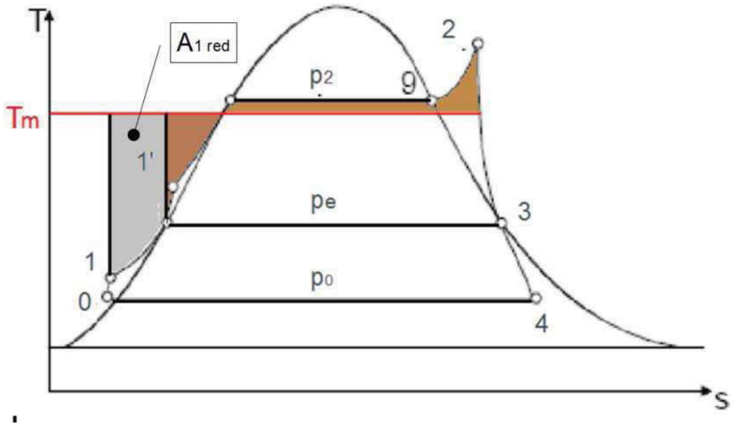


Figure 83: *CRC including preheating T – S diagram [modified 11]*

The thermodynamic sense of the preheating system does not reveal at first sight. Normally a number of turbines are used (not just one like in the schema) after the steam has done mechanical work in a turbine, a small part of it is directed to preheat the condensed feeding water. The major part of it is directed to the next turbine where again the steam is split after having performed mechanical work.

As mentioned before, the furnace bulk temperature Tm is governing the total efficiency of the process. Graphically it was illustrated in **Figure 77**, as discussed before Tm can be graphically constructed as the temperature where both areas are equal.

If the required heating energy for heating up the liquid water to boiling point originates from another source, as the primary heating source in the boiler, area 2 becomes smaller and Tm rises. This is illustrated in Figure 83 where, the greyish area ($A1_{Red}$) is covered by a bypassed steam increasing the furnace bulk temperature and therefore total efficiency.

Because of the high enthalpies of the bypassed steam only relatively small amounts have to be bypassed reducing the next turbines power, summing up both effects the feed water preheating results in efficiency increases that are comparable to the reheating process. (If enough stages are included - In modern fossil power plants there are seven and more stages).

Smaller geothermal powerplants can be built as single double or multistage, this refers to the number of turbines and the possibility to include reheating or feed water preheating

13.8 Geothermal energy usage in classic fossil power plants

The described feed water preheating suggests a usage of geothermal energy. The question is: Does it make sense to substitute the energy taken from the turbines to preheat the feed water with geothermal energy? Further investigation will be done in the according project description.

13.9 Low temperature power plants

[Information for chapter 18.9 and subtitles is taken from 13]

In classic fossil power plants water is heated up to 500°C and more, applying pressures of more than 250 bar in the first stage, which yield to electric net efficiencies of clearly above 40 %

Temperature levels of below 250 °C are not able to increase the steams enthalpies to high enough levels for classic power plants. A technical solution of this problem is the utilization of carrier media different from water, which offers a lower boiling point (ORC process [Organic Rankine Cycle]); or to reduce the boiling point of water by adding for example ammoniac (Kalina process)

Basically there are two power plant types applied

1.) Organic Rankine Cycle (ORC) power plants
2.) Kalina power plants

13.9.1 Organic Rankine Cycle (ORC) power plants

Organic Rankine Cycle (ORC) power plants

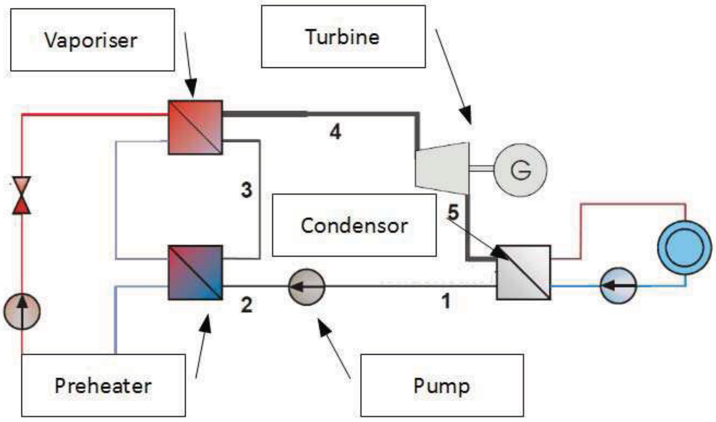


Figure 84: Schema of a simple Organic Rankine Cycle process [12]

Basically the process does not differ much from a standard CRC (Clausius Rankine Circle), however a different working media than water can be used, the geothermal heat energy is used to vaporise a liquid organic matter, and to preheat the power plants backflow before being used in a heating network and finally being reinjected.

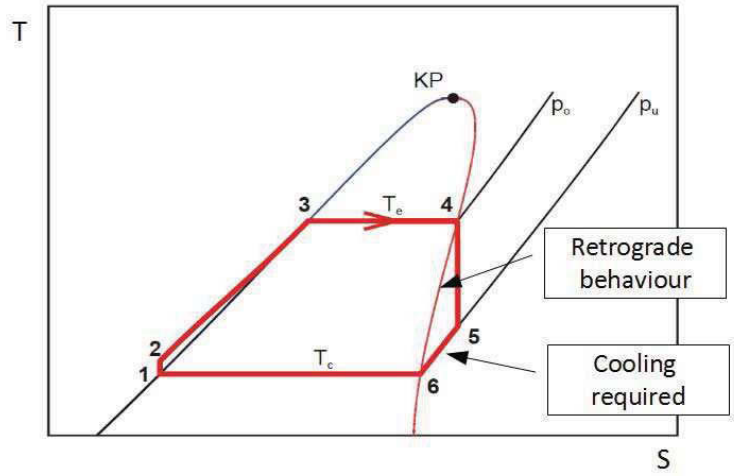


Figure 85: *T – S diagram of a typical ORC process [13]*

1-2 Increasing pressure

2 -4 Heating (2-3 heating liquid to boiling point; 3 -4 vaporising)

4 – 5 performing mechanical work in turbine

5 – 6 Cooling

6 – 1 Condensing

Differences to the classic CRC process are that due to the retrograde behaviour of the media additional cooling is required to reach the dew line and allow condensing. Additionally there is no superheating of vapour.

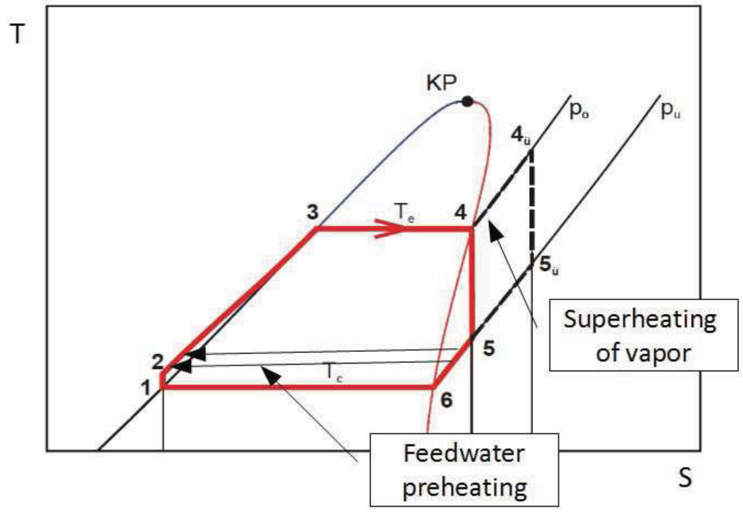


Figure 86: *Classic improvements imbued on an ORC process [13]*

Superheating of vapour obviously makes no sense; all additionally delivered heat energy has to be cooled down in step (5 – 6) to reach the dew line, due to the retrograde behaviour of carrying media.

The black arrows shall represent a heat transmission from the cooling to the preheating. It is thermodynamically seen not correct to illustrate heat energy transfer in a T-S diagram like that! But because it has been described before, this is accepted for visualisation. As in classic processes feed water preheating yields to an increased efficiency, however due to the usually strong reduced number of stages (<= 2) the impact is also smaller.

Further improvements of the efficiency can be reached optimizing working fluid.

13.9.2 Kalina cycle power plants

The Kalina Cycle processes are a family of different applications for low temperature power plants; they have in common the usage of a mixture of ammoniac and water as working media. One example, which is suitable for geothermal temperatures in the Molasse basin, will be discussed.

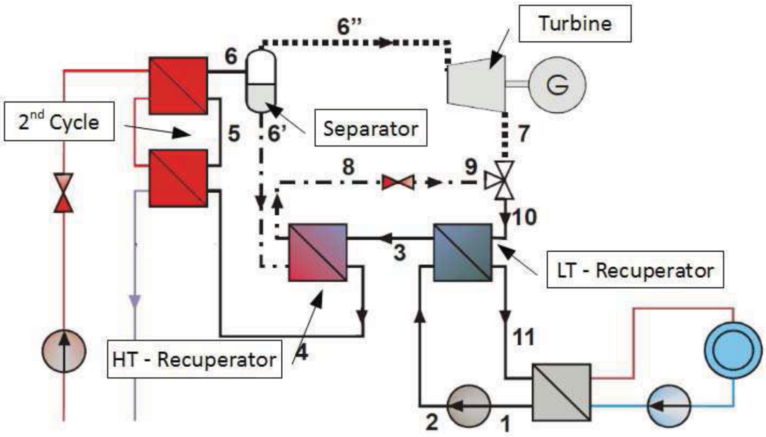


Figure 87: Schema of a Kalina cycle process [12]

In a peanut this arrangement uses ammoniac enriched water dissolution as working media. Which is preheated and vaporised in the 2^{nd} cycle, in the separator they vapour is split in an ammoniac rich and a water rich dissolution. The ammoniac rich one is directed to the turbine to perform mechanical work. The water rich one is directed to the recuperators used as preheating, utilizing also the adsorption energy of the ammoniac enriched dissolution from the turbine. This has basically, thermodynamically seen the same effect as classic feed water preheating, utilizing different physic chemical properties of ammoniac water mixtures.

To understand the exact details of this process original literature is referenced. [“Geothermisch angetriebene Dampfkraftprozesse Analyse und Prozessvergleich binärer Kraftwerke” -Silke Köhler]

13.9.3 Comparison of both power plant types

Following characteristics are important to compare the application benefits of both power plant types:

1.) Achievable backflow temperature (= attached heating networks forward flow)
2.) Efficiency vs. Temperature
3.) Investment costs (vs. Temperature)

Achievable backflow temperatures

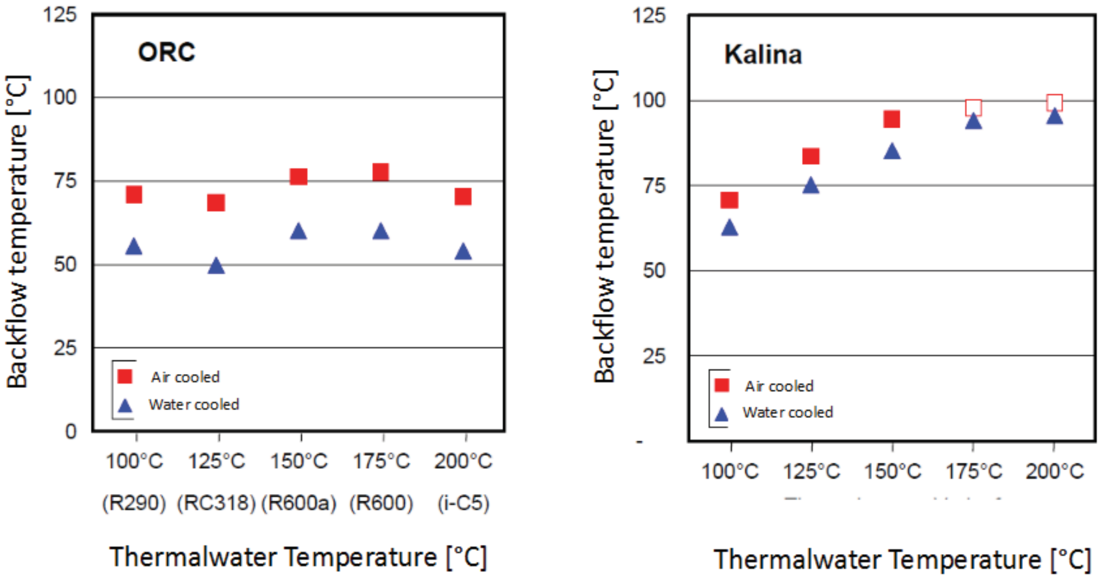


Figure 88: Power plants backflow temperatures [13]

In general it has to be stated, that the ORC process cools down the Reservoir more than the Kalina process. Assuming a large scale project, it is economically and by federal requirements (to get support) necessary to utilize backflow energy for heating purposes. Larger networks will need at least forward flow temperatures of 85°C, which cannot be achieved by the ORC process. Kalina power plants offer high enough back flow temperatures if forward flow temperatures of more than approximately 120 - 140°C are utilized.

If an ORC or a Kalina power plant with too low forward flow temperature, is attached to a community network a part of the geothermal water has to be bypassed the power plant, being mixtured with the power plants backflow to achieve suitable network temperatures, further reducing electric net efficiency. Alternatively the heating energy also could be levelled up by a heat pump or supported by another additional heat source.

From the heating support point of view, Kalina technology is preferable. ORC process with water (or also air) cooling will most likely offer too low backflow temperatures, for a reasonable rest heating energy usage.

Please note that a high backflow temperature also indicates a low amount of energy used in the process, not only low heating energy usage potential.

Efficiency vs. temperature comparison between ORC and Kalina process

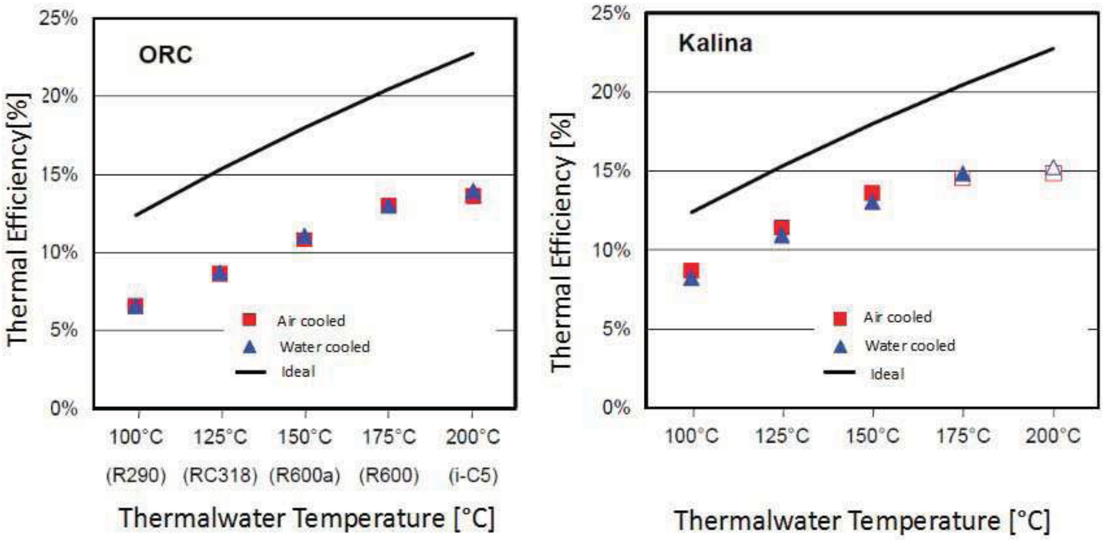


Figure 89: *Thermal efficiency of ORC and Kalina power plants [13]*

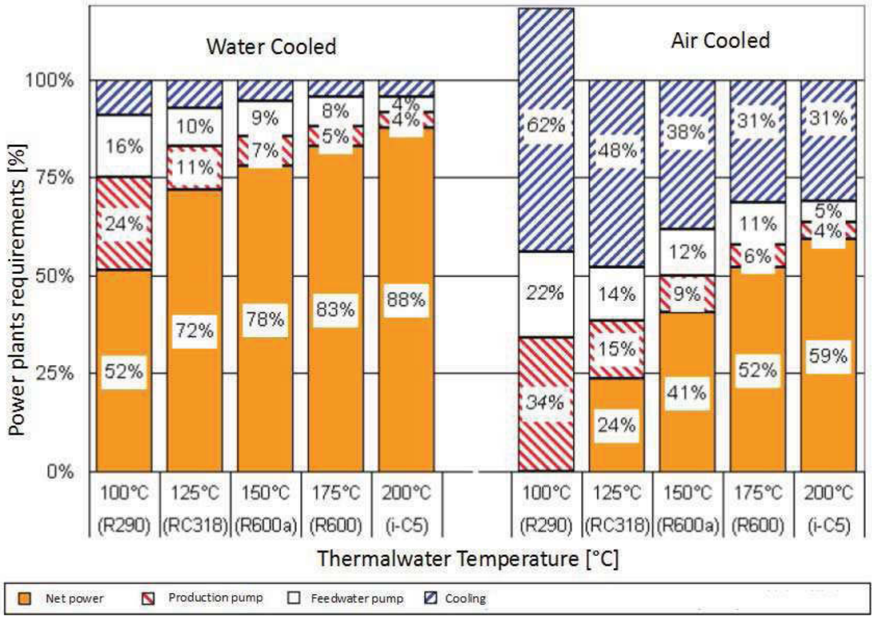


Figure 90: *ORC power plants electricity requirements [13]*

Yellow: Net Power; Red: Production pump; White: Feed water pump; Blue: Cooling

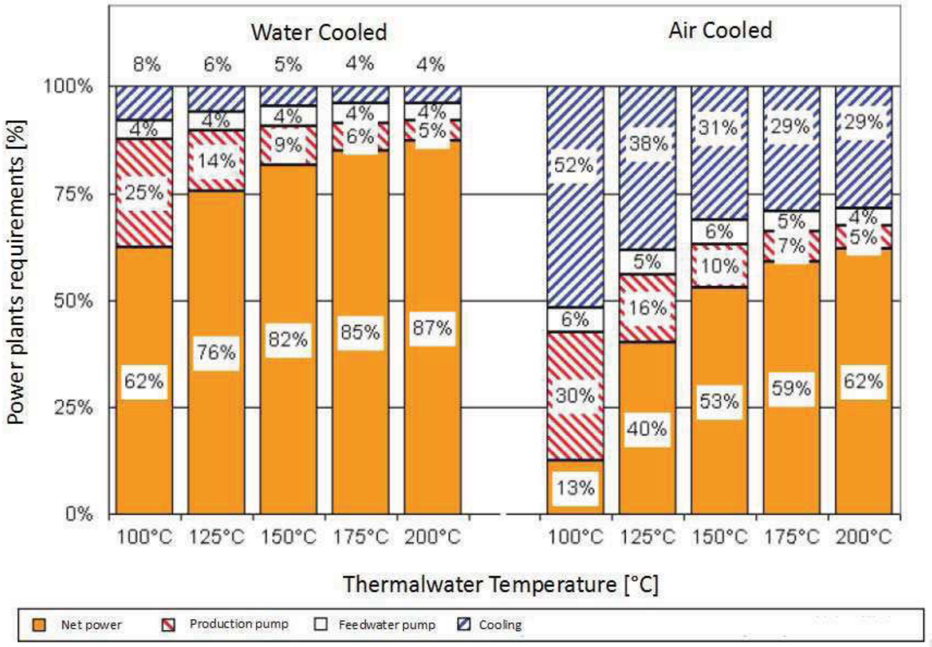


Figure 91: ORC power plants electricity requirements [13]

Yellow: Net Power; Red: Production pump; White: Feed water pump; Blue: Cooling

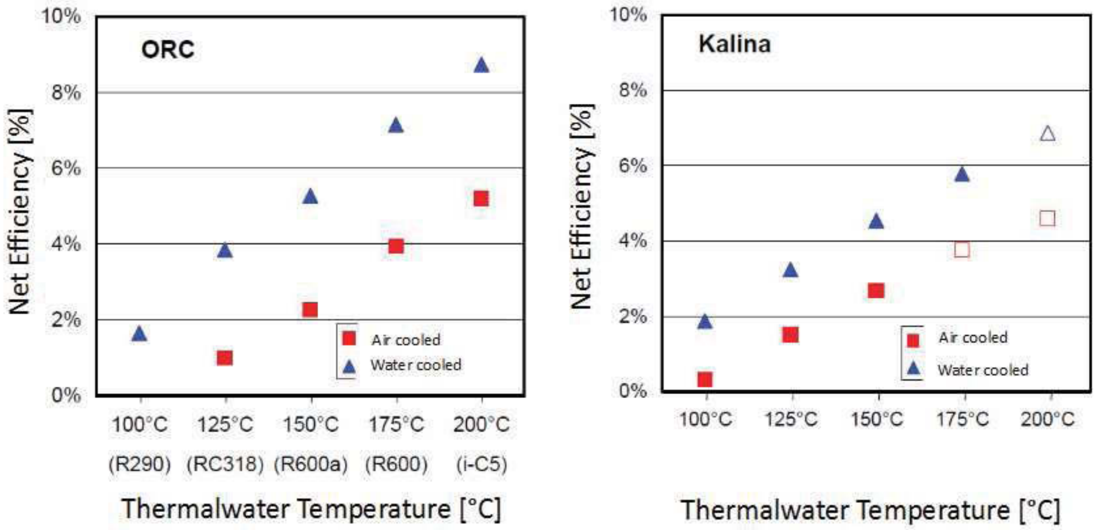


Figure 92: Net efficiency of ORC and Kalina power plants [13]

Illustrated is the net efficiency for geothermal power plants, at a temperature range from 100°C to 200°C. Net efficiency means here, all system losses included (Turbine and Generator losses, electricity demand of power plant, and production pump for a dynamic water level of 200 m beneath surface and a production rate of 20 kg/s [13]

As discussed most likely ORC water cooled technology is most probably not an option, due to required minimum temperature for heating energy usage.

Note that the net efficiency graph does not only take thermal efficiencies and power demand into account, but also the amount of energy that can be utilized by the process, which is defined by the backflow temperatures.

The higher cooling down of the reservoir water in the OCR process, pushes the net efficiency above those of Kalina power plants (if T > 150 °C air cooled; T > 110°C water cooled), even though Kalina power plants offer a better thermal efficiency and lower electric energy demand

13.9.4 Investment costs of discussed low temperature power plant types

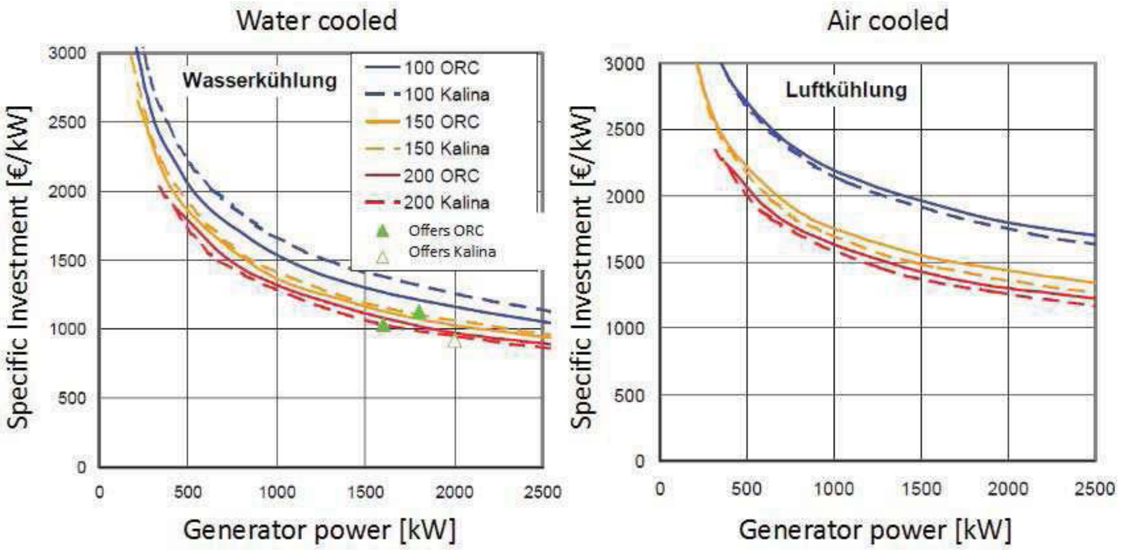


Figure 93: Specific Investment costs geothermal power plants [13]

Water and air cooled ORC and Kalina power plants for geothermal temperatures of (100 °C 150°C and 200°C) and generator sizes of up to 2,5 MW

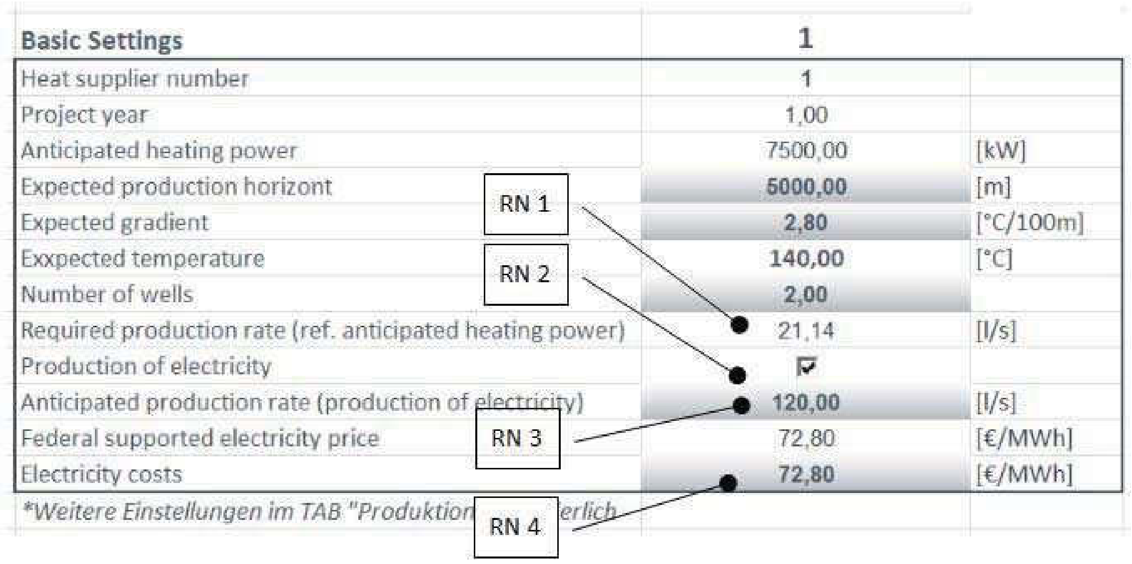
Especially in the for Kalina application interesting lower Temperature range, these power plants have higher investment costs. This is due to the corrosive behaviour of ammoniac, resulting in high quality material required.

In Germany there is one Kalina power plant in Unteraching near Munich on line, producing gross electric power of 1, 7 MW, and part of the rest heating energy is fed to an existing community heating

14 Evaluation software – Geothermal wells

Task of this part of the software is to pre design geothermal wells. Necessary demand analysis, network planning and energy concept, need to have been performed at least in the "rough estimation" mode. The output is a predesign of the well according to the energy demands, an estimation of investment costs and an approximation of the production pumps electricity demand

14.1 Basic settings in module "Overview"



Basic Settings	1	
Heat supplier number	1	
Project year	1,00	
Anticipated heating power	7500,00	[kW]
Expected production horizont	5000,00	[m]
Expected gradient	2,80	[°C/100m]
Exxpected temperature	140,00	[°C]
Number of wells	2,00	
Required production rate (ref. anticipated heating power)	21,14	[l/s]
Production of electricity	☑	
Anticipated production rate (production of electricity)	120,00	[l/s]
Federal supported electricity price	72,80	[€/MWh]
Electricity costs	72,80	[€/MWh]

*Weitere Einstellungen im TAB "Produktion erlich

__Figure 94__: Basic Project settings in "Overview" [own illustration]

***RN1:** required production rate (ref. anticipated heating power)*

This production rate is calculated according to the energy concept settings and the geothermal and network temperatures, in a way to satisfy the planned supply.

***RN2:** Production of electricity*

If this is ticked on the required production rate is overruled by the anticipated production rate

***RN 3:** Anticipated production rate*

The production rate desired if the well is designed to serve an electricity power plant as heat source. (Only active if RN2 is set "on")

***RN4:** Electricity supported price and costs*

The supported price is calculated according to the country in which the project is located, and additional settings which are not illustrated here.

In some projects juridical trickery is done to improve the economics. Cheap electricity from the net is bought to serve e.g. the production pump, so that more energy originating from the power plant can be sold at the supported high price. This works by juridical splitting of the geothermal well and the power plant, in other words the power plant owner is not the geothermal well owner; the energy is sold to the power plant, which uses it to produce electricity. As the geothermal well, does not belong to the power plant the production pump is not classified as “own demand”, the geothermal well owner can buy electricity from the net, which can significantly increase the overall economic of the project

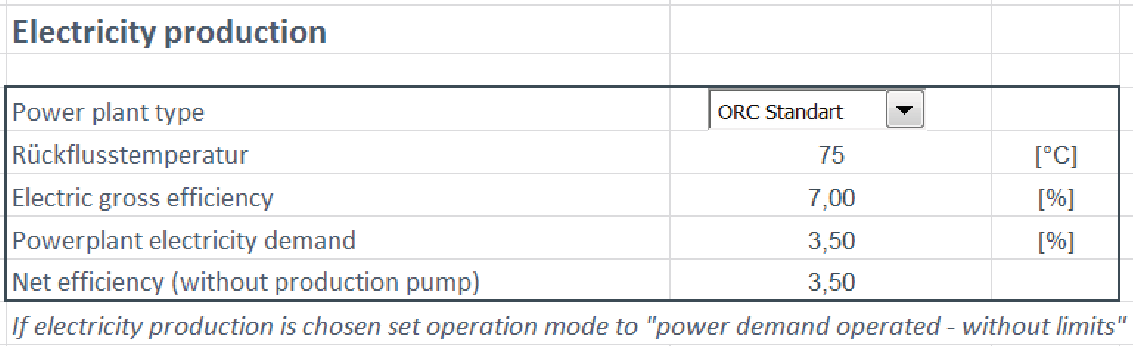
It shall be mentioned, that the author condemns behaviour like this. It is simply wrong, if companies do projects, in which revenues originating of at least 40 to 80 % from the state, and cheap credits, investment support and insurances are given, to capitalise additional federal support in obvious intend to defraud, instead of planning reasonable projects.

Nevertheless the software allows investigating these effects. Normally electricity cost should be set on the same value as the price to threat the production pump costs as “own demand”

14.2 Program module “Production”

This module helps to evaluate necessary casing design, well path and their influence on power demand of production pump. Further it evaluates necessary heat energy power plant bypass for heating network demand, as discussed previously. Additional a basis for wellbores cost evaluation is given.

14.2.1 Electricity production



Electricity production

Power plant type	ORC Standart	
Rückflusstemperatur	75	[°C]
Electric gross efficiency	7,00	[%]
Powerplant electricity demand	3,50	[%]
Net efficiency (without production pump)	3,50	

If electricity production is chosen set operation mode to "power demand operated - without limits"

***Figure 95**: Additional settings for electricity production in “Production” [own illustration]*

Different power plant types referencing to them discussed in the theoretical part. (E.g.: ORC Standard = ORC air cooled; ORC water cooled; Kalina air and water cooled;

Backflow temperature, Electricity gross efficiency (= Thermal efficiency) and power plant electric own demand are calculated according to the data given in 13.9. The power demand of the production pump is calculated according to the following chapters

Importance of electricity demand of production pump

Please note that the production pump in large scale projects will require several 100 kW, which is relatively high compared to net electricity power outputs between 0, 0 and 2 MW.

Economic impact of saving 100 kW production pump demand

Assumptions: project life time: 20 years; internal rate of return 7%; (constant) federal supported electricity price: 240 €/MWh; Hours per year online: 8600 h

Resulting in energy savings per year: ~ 200.000 €

Depreciated value over project life time: ~2.250.000 €

(Assuming saving power produced in a geothermal power plant)

The author expects, that wellbore planning which considers minimum production pump requirements as a main target, has probably a very high potential, this is why the evaluation software pays that much attention to it.

14.2.2 Wellbore pre design

Overview Wellbores

	Type	P/I Rate actual settings	P/I Rate own settings	TVD Target	Chosen casing program	Total pressure loss	Temeperature actual settings	Temperature own settings
Wellbore 1	Production w.b.	120	0	5000	LC 8 5/8"	29	140	0
Wellbore 2	Injection w.b.	120	0	2600	LC 8 5/8"	35	55	0
not defined	Injection w.b.	0		0		#NV	0	
not defined	Injection w.b.	0		0		#NV	0	

active Wellbore	Wellbore 1	production rate	120
		production rate (ST)	0

	Typ	TVD	Inclination	MD - Casing	MD	average T formation	Wandrauigkeit	approx average density
				von	zu			
		[m]		[m]	[m]	[°C]		
Sektion 1	Casing	300	0	300	0	4,2	0,2	998
Sektion 2	Liner	2000	0	2100	200	32,2	0,2	980
Sektion 3	Liner	2800	25	3100	2000	67,2	0,2	959
Sektion 4	Liner	3300	60	3883	3000	85,4	0,2	944
Liner Overlap	100							

		Diameter	from MD	length	anticipated PR	expected T	pipe roughness	pressure loss
		[in]	[m]	[m]	[l/s]	[°C]		
Sidetrack	☐ Ja	8 5/8"	3100	500	50	130	0,2	#DIV/0!

Figure 96: Predesign settings of wellbore [own illustration]

RN 1

In “Overview Wellbore” all production and injection wells are defined

RN 1a

Type of Wellbore (Injection or Production) well needs to be defined. This defines e.g. the wellbore fluid temperature.

RN 1b

The production rate settings are displayed according to the settings in overview. If there is more than one well producing or injecting, the total production rate is distributed evenly between the wells. In “own setting” this can be changed. IF “own” setting contains a number different from zero it overrules the previous settings

RN 1c

The casing program is imported after the predesign is done.

RN 1d

The temperature settings are taken from the “overview” spread sheet. For injection wells this is either the backflow of the power plant or the network

RN 2

From the defined wellbores one has to be active to start the pre design of well path and casing design.

RN 2.a

The casing type has to be defined: Liner or Casing

RN 2.b

Well path is defined by TVD, Inclination and MD (Wellbore radius is neglected at this point) Additional the MD of the casing shoe can be set, as it doesn’t have to be equal to the section depth.

RN 2.c

According to the temperature and total vertical settings, values such as water density and viscosity are interpolated from tables per section, which are used in the pressure loss calculation

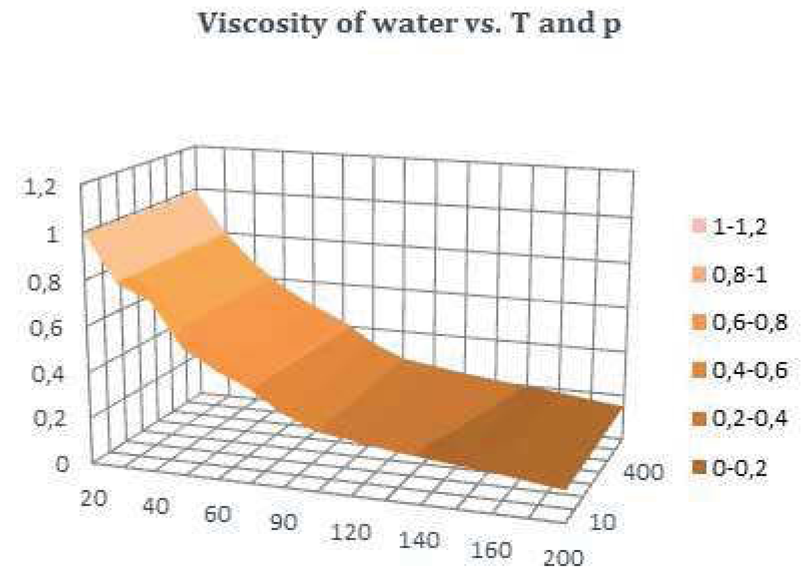


***Figure 97**: Viscosity of water depending of temperature and pressure [own illustration]*

RN 2.d

A side track can be defined according to the illustrated settings, to take a part of the production rate.

Display of well path pre design

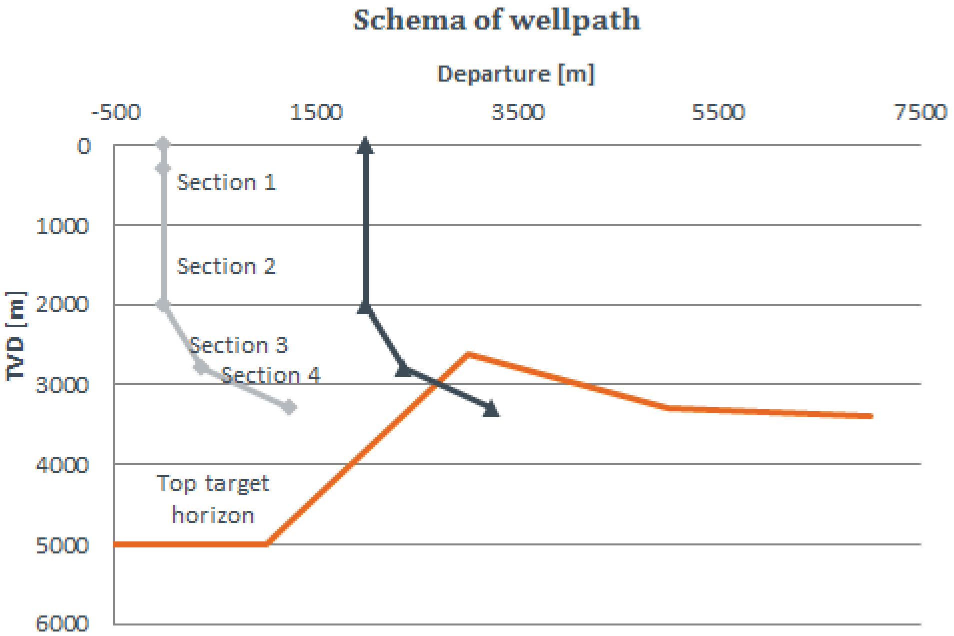


Figure 98: *Illustration of well path [own illustration]*

(No reasonable well paths displayed)

Note that this illustration does not take notice of different cardinal points or the correct display of the departure between the wells.

It just displays settings measured depth and true vertical depth of the individual wells, the perspective is chosen in a way, that the angles are displayed correct assuming the well does not change its azimuth.

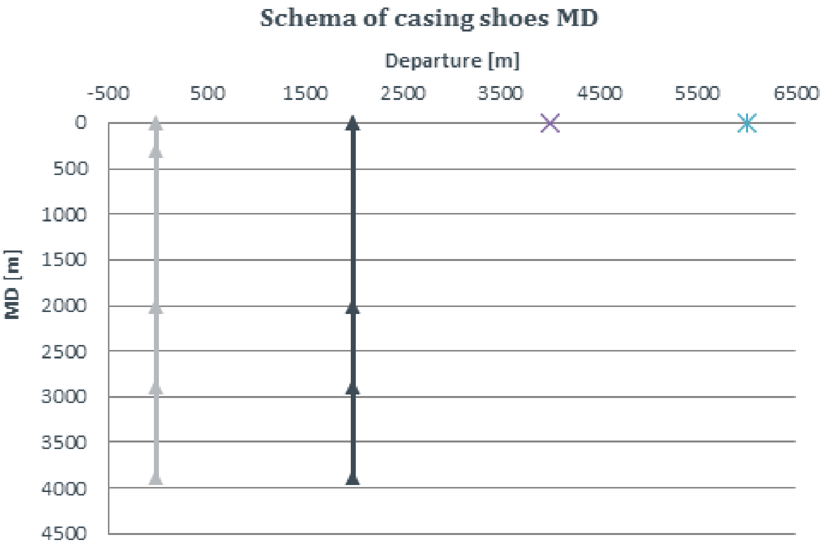
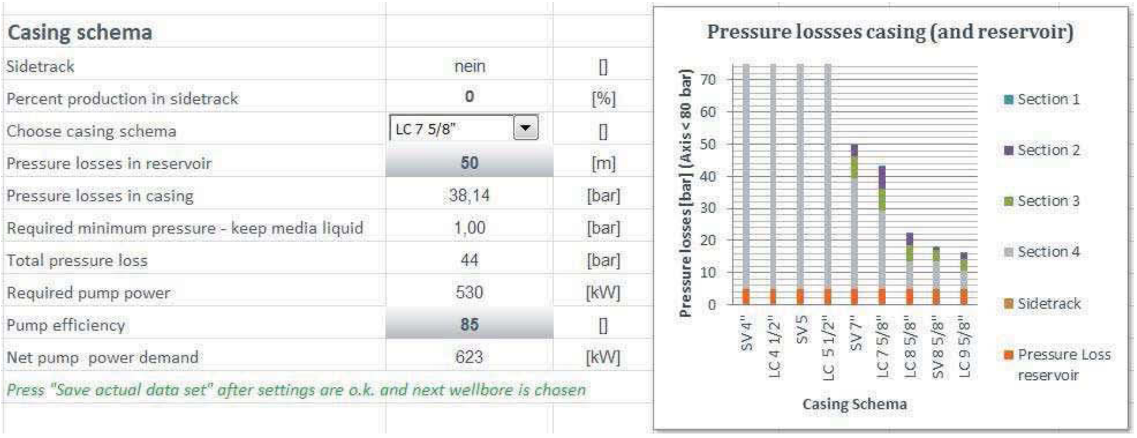


Figure 99: *Schema of casing shoes measured depth [own illustration]*

Additional also the MD of the casing shoes is displayed.

14.2.3 Choose fitting casing design



Casing schema		
Sidetrack	nein	[]
Percent production in sidetrack	0	[%]
Choose casing schema	LC 7 5/8"	[]
Pressure losses in reservoir	50	[m]
Pressure losses in casing	38,14	[bar]
Required minimum pressure - keep media liquid	1,00	[bar]
Total pressure loss	44	[bar]
Required pump power	530	[kW]
Pump efficiency	85	[]
Net pump power demand	623	[kW]

Press "Save actual data set" after settings are o.k. and next wellbore is chosen

Figure 100:*Casing design [own illustration]*

According to the measured depth of casings, and the physical properties of water evaluated referring to the given temperature settings. The program calculates expected pressure losses of various casing designs. The planner can choose a fitting casing design and adapt the well path, than export the data to overview and visualise the impact on the total economics.

Please not the difference between an LC 8 5/8 and a LC 7 5/8” casing schema: approximately: 20 bars. At a production rate of 120 l/s and a pump efficiency of 85 % this would create an additional pumping electric energy demand of 280 kW. According to the settings of “Importance of electricity demand of production pump” this would yield:

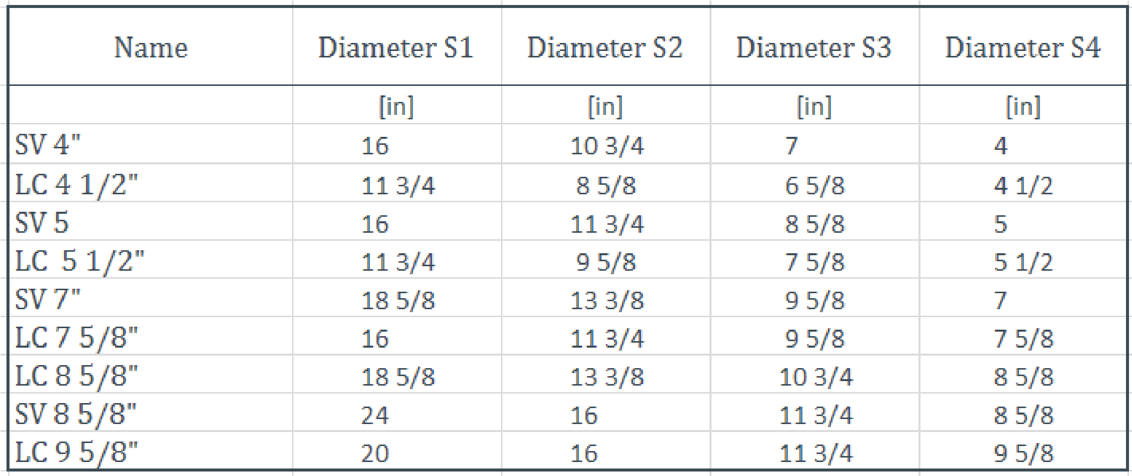
Energy savings of 560.000 €/year

Additional depreciated project value: 6.300.000 €

(Assuming saving power has the value of energy produced in a geothermal power plant)

Even though this will not be exactly true as the casing diameter also influences the production rate from the formation to the well even in a fracture permeable well, the saving potential stays large.

If a fitting design is found, the data can also be exported to well costs to find an approximation of wellbore investment cost.



Name	Diameter S1	Diameter S2	Diameter S3	Diameter S4
	[in]	[in]	[in]	[in]
SV 4"	16	10 3/4	7	4
LC 4 1/2"	11 3/4	8 5/8	6 5/8	4 1/2
SV 5	16	11 3/4	8 5/8	5
LC 5 1/2"	11 3/4	9 5/8	7 5/8	5 1/2
SV 7"	18 5/8	13 3/8	9 5/8	7
LC 7 5/8"	16	11 3/4	9 5/8	7 5/8
LC 8 5/8"	18 5/8	13 3/8	10 3/4	8 5/8
SV 8 5/8"	24	16	11 3/4	8 5/8
LC 9 5/8"	20	16	11 3/4	9 5/8

Figure 101: *Casing design schemas [own illustration]*

LC = Low Clearance Solution

14.2.4 Temperature levels and necessary power plant bypass

The program also displays an illustration of temperature levels and possible bottlenecks according to the actual settings.

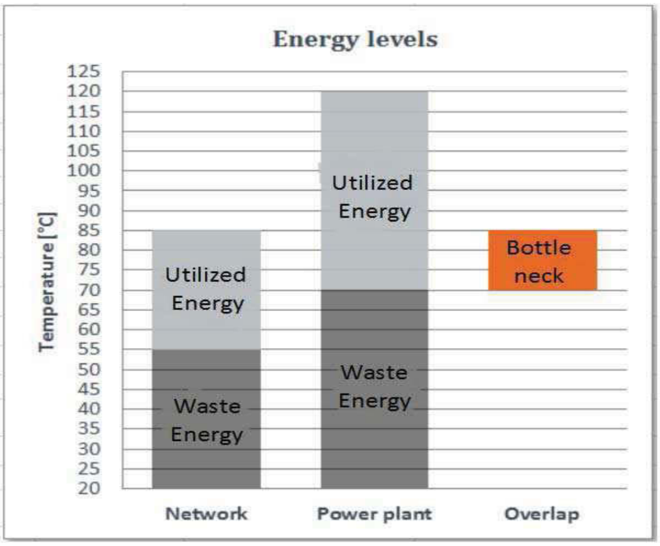


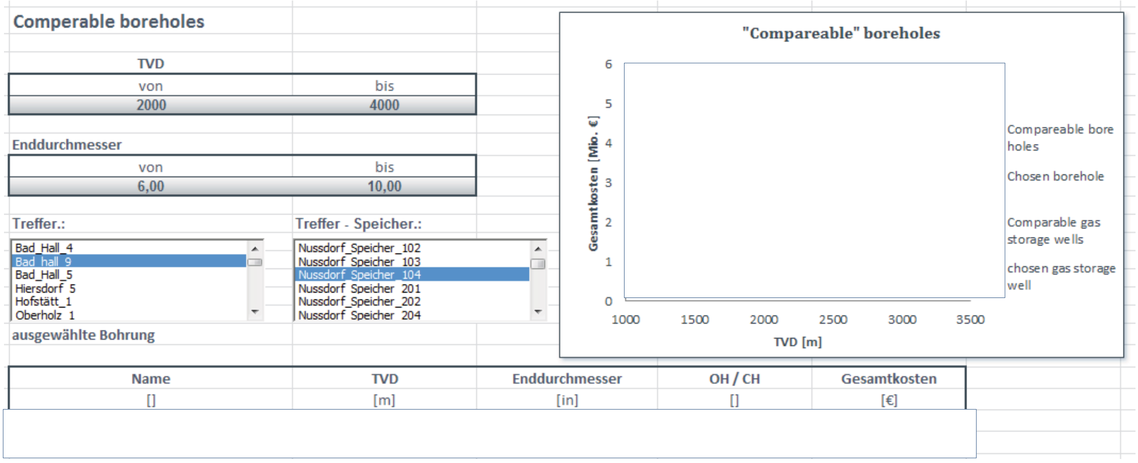
Figure 102 *Temperature bottleneck [own illustration]*

Illustrated is the energy level demand of the network and the power plant. In an ideal case the power plants backflow has the same level as the networks forward flow. In most geothermal applications however the backward flow of the power plant will be too low, as illustrated in the example. An overlap occurs resulting in an energy bottle neck.

To overcome this problem an additional heat source can be planned which levels up the power plant backflow. Another possibility is the described bypassing of geothermal water before entering the power plant to mix it with power plant backflow water achieving fitting network temperatures.

The amount of bypassed energy and the effects on net electricity production are calculated automatically by the program.

14.3 Program module “Well bore cost approximation”



Comperable boreholes

TVD

von	bis
2000	4000

Enddurchmesser

von	bis
6,00	10,00

Treffer.:

Bad_Hall_4
Bad_hall_9
Bad_Hall_5
Hiersdorf_5
Hofstätt_1
Oberholz_1

Treffer - Speicher.:

Nussdorf_Speicher_102
Nussdorf_Speicher_103
Nussdorf_Speicher_104
Nussdorf_Speicher_201
Nussdorf_Speicher_202
Nussdorf_Speicher_204

ausgewählte Bohrung

Name	TVD	Enddurchmesser	OH / CH	Gesamtkosten
[]	[m]	[in]	[]	[€]

Figure 103: Compare able bore holes (RAG data cleared in public version) [own illustration]

For a first cost estimation already drilled compare able oil, gas and gas storage wells can be investigated. The programme request maximum and minimum true vertical depth (TVD) and end casing diameter values (ECD).

Reference bore holes are searched from lately drilled (since 2005) wells of the RAG.
Displayed are:
TVD; ECD; completion type and total costs.

Additional the program offers an evaluation tool for:

1.) Casing predesign and costs
2.) Cement predesign and costs
3.) Mud predesign and costs

Providing cost data to an evaluation cost sheet.

This part of the program contains data from RAG itself and sub-contractors, which is considered sensitive and will not be described here.

Nevertheless an average cost distribution of a conservative planned 4500 m well with and ending diameter of 8 ½ inch is given

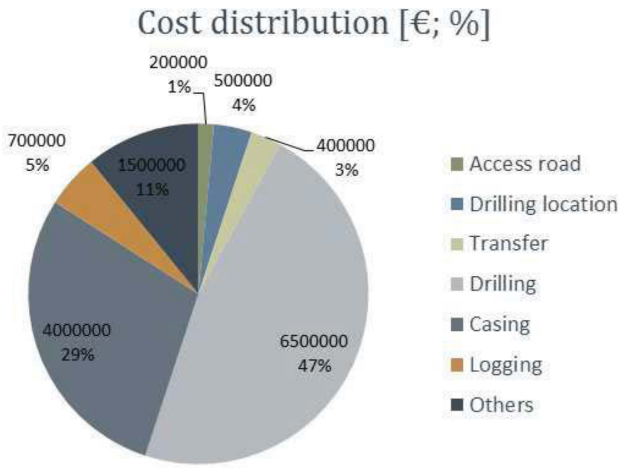


Figure 104: *Cost distribution of one producing well [own illustration]*

For a well of approx. TVD 4500m ending diameter 8 ½"

As illustrated the total costs are approximately 14 Mio € for one producing well (injecting wells are normally slightly cheaper, due to lower deviation and temperatures)

The major part, with almost 50% is drilling itself, including rig day rate, drill bits, mud service, mud itself, measuring while drilling service and other tools. Also important are the material costs of the casing string with almost 30 % of total costs. The rest is due to rig location, rig transfer, logging and others.

Not included are mud recycling and insurances.

Please note that bore hole costs increase exponential to the depth.

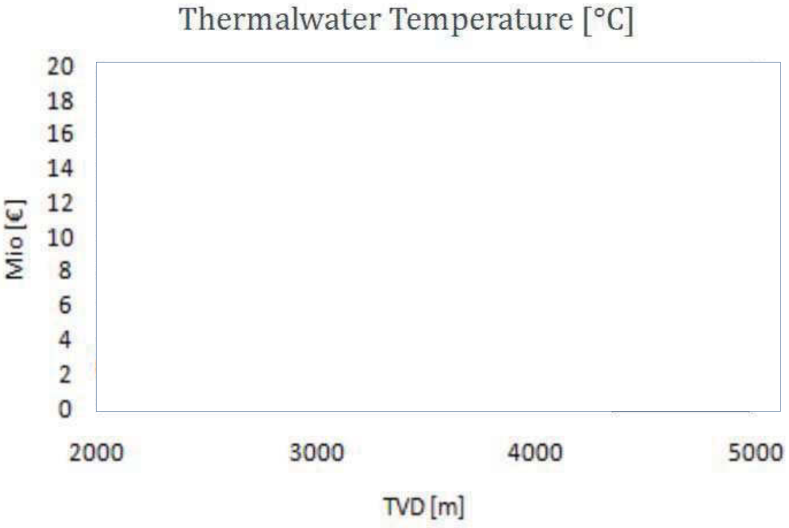


Figure 105: Range of oil and gas bore hole costs in the Molasse basin [own illustration, based on RAG data] (RAG data cleared in this version)

15 Large scale projects including geothermal wells

This chapter will describe projects that include geothermal wells, even though not all of them would have been first choice projects.

Described project types

1.) Large scale geothermal heating energy supply
2.) Large scale geothermal heating and electric energy supply
3.) Feed water preheating of fossil power plants with geothermal energy

15.1 Large scale geothermal heating energy supply

15.1.1 Comment

Please note that the following project description is done in the rough estimation mode; it is not a case study. It is a try to visualise the characteristics of such a project. It was not target to try to demonstrate exact values, which also would not make sense in a made up example In this mode basically the achievable revenues (including most important operation costs) there origination and major influences on them are illustrated, investment costs which are strongly dependent on local circumstances are given as possible ranges.

15.1.2 Project set up

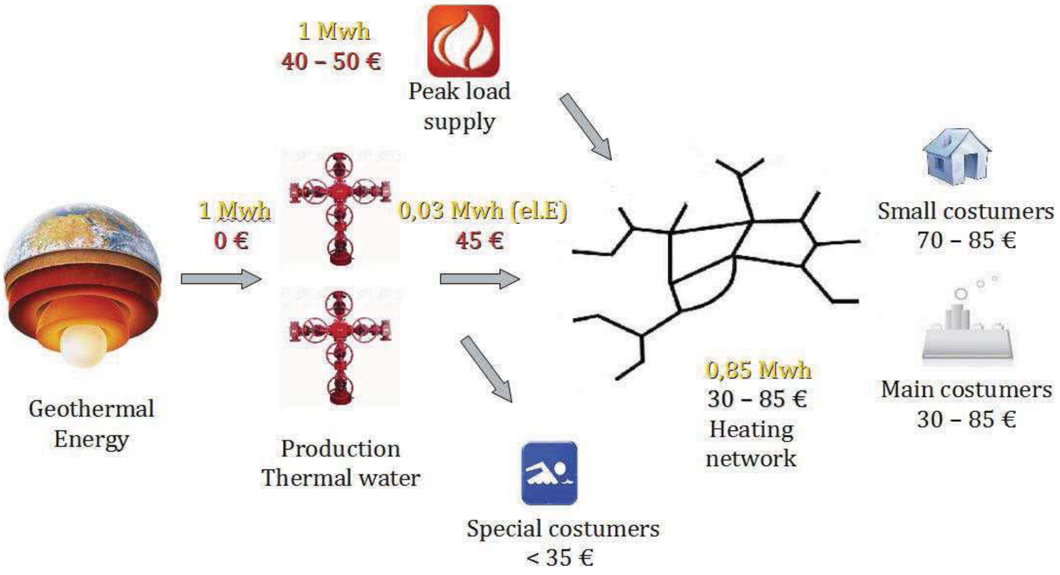
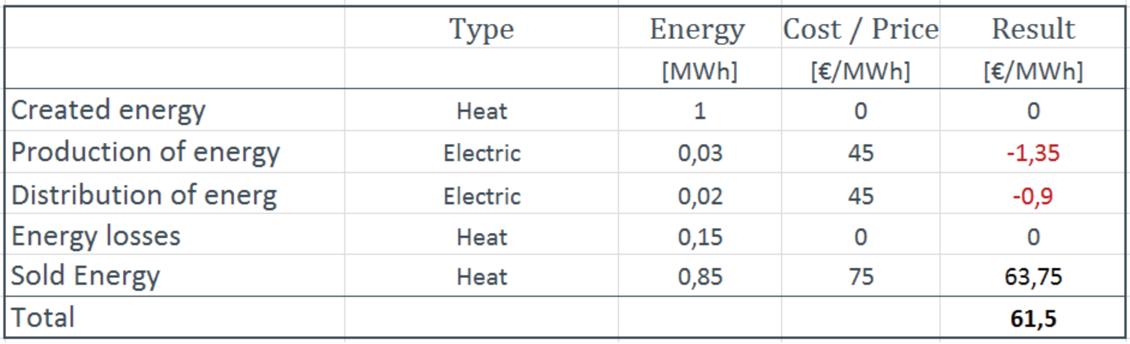


Figure 106: *Project set up of a large scale geothermal heating energy supply [own illustration]*

Illustrated are origination and costs (red) / price (black) of energies. The energy originates from a geothermal reservoir, without causing costs. It is produced and injected via pumps requiring approx. 0,003 MWh / produced MWh electric energy for 45 €/MWh. Due to network losses approximately 0,85 MWh / MWh reaches the costumer, being sold for 30 – 85 €/MWh depending on the costumer type. Peak load energies causes costs of 40 to 50 €/MWh due to fuel demand. Running network costs are not considered in this graph.

15.1.3 Theoretical creation of value



	Type	Energy	Cost / Price	Result
		[MWh]	[€/MWh]	[€/MWh]
Created energy	Heat	1	0	0
Production of energy	Electric	0,03	45	-1,35
Distribution of energ	Electric	0,02	45	-0,9
Energy losses	Heat	0,15	0	0
Sold Energy	Heat	0,85	75	63,75
Total				**61,5**

Figure 107: *Theoretical creation of value per MWh [own illustration]*

As illustrated a project like this would theoretically create a value of 61, 5 € / MWh, depending on the costumer structure.

15.1.3.1 Most important influences on economics – Geothermal projects

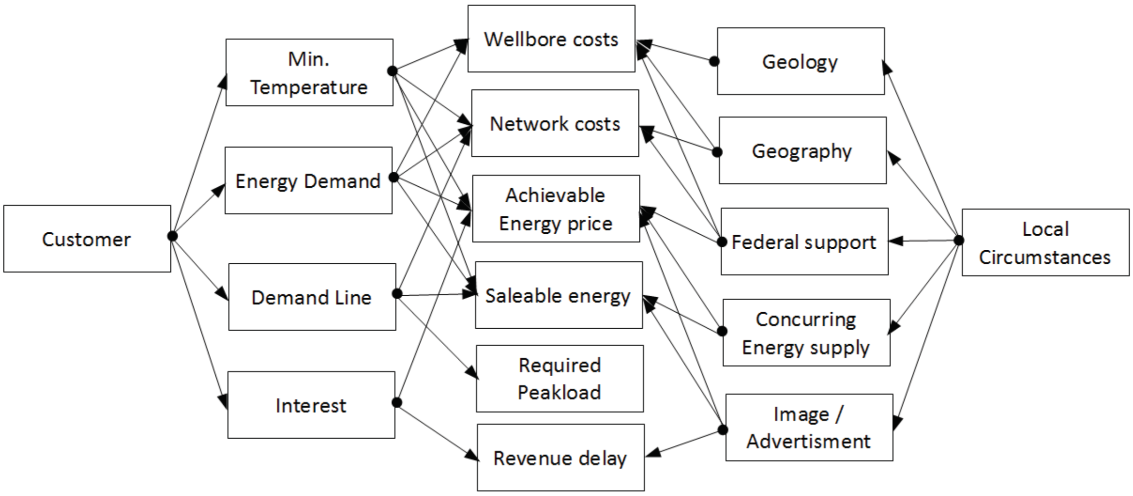


Figure 108: *Most important influences on economics – Geothermal projects [own illustration]*

Illustrated are the most important influences on the major factors on economics of a large scale geothermal heating supply project

Wellbore costs:

Minimum Temperature -> Total Vertical Depth
Energy Demand -> Casing Schema
Geology -> Total Vertical Depth
Geography -> Bore hole Location (Measured Depth)

Network costs

Minimum Temperature -> Required Diameters
Energy Demand -> Required Diameters
Geography -> Pipelines length
Federal support -> Investment costs

Achievable energy price

Minimum Temperature -> Low temperature levels (fish tank) achieve low price
Energy demand
Interest
Concurring Energy -> Price to push out existing supply
Federal support -> Support for costumer's home stations

Saleable energy

Temperature -> Some costumers might require higher T than produced
Energy demand
Demand line -> Peak load supportable?
Concurring Energy
Image / Advert.

Required peak load

Demand Line

Revenue delay

Costumer Interest
Image / Advert.
(Achieve able Price)

Operation costs

Pumping power requirement

Please note, that the mentioned coherences are only the most important ones and by far not complete, as various factors also influences each other. Due to the high complexity of such a project, it is not really possible to present a standard solution or a standard sensitivity analysis. In the following example it is tried to point out the very basics of these project type.

15.1.4 Example large scale project geothermal heating supply

All calculations done in "rough estimation" mode

Demand structure

Large town with 20.000 inhabitants and 10 MW industrial heating demand (<95°C)

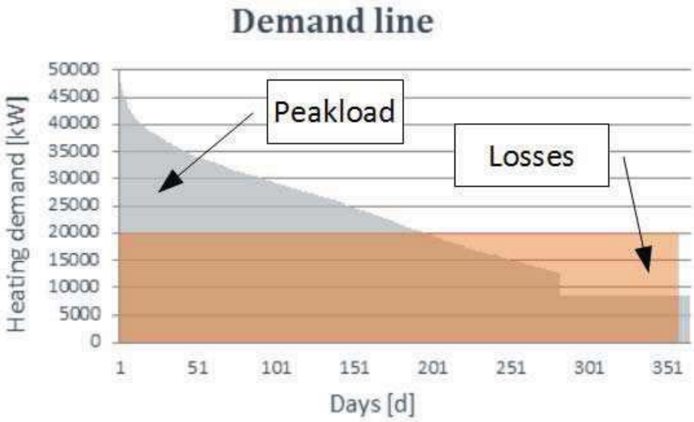


Figure 109: *Examples demand line [own illustration]*

Network

Forward / backward flow:	85/ 45 °C
Customer behaviour	(25/90/15log) [Start value/End value/Delay/Function]
Average achievable profit:	70 €/MWh (geothermal energy)
Average achievable profit:	35 €/MWh (peak load)

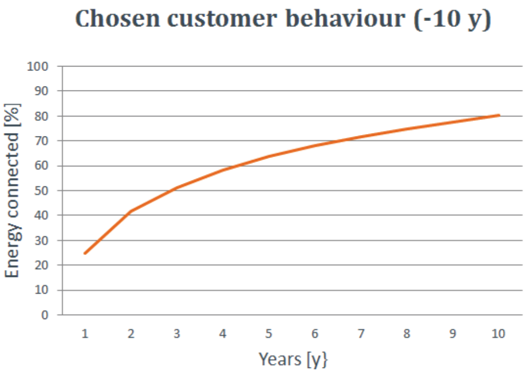


Figure 110: *Examples costumer behaviour [own illustration]*

(Including delay due to network build up)

Wellbore

Produced energy:	20 MW (exclusive Net losses)
Temperature:	100 °C
TVD	3300 m
Production rate:	~ 90 l/s
Casing schema	Standard 7" ending diameter

Economics

Anticipated internal rate of return:	7 %
Project life time	20 y

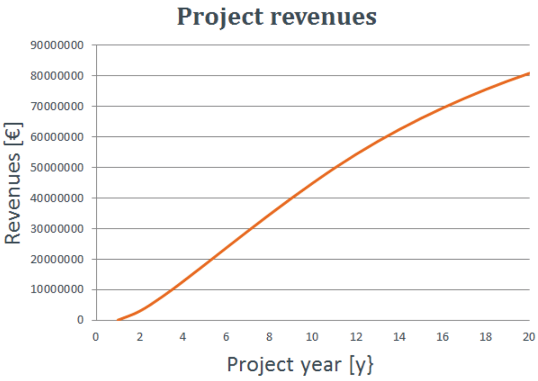


Figure 111: *Example project revenues [own illustration]*

According to the actual settings the project value after 20 years would be approximately 80 Mio €

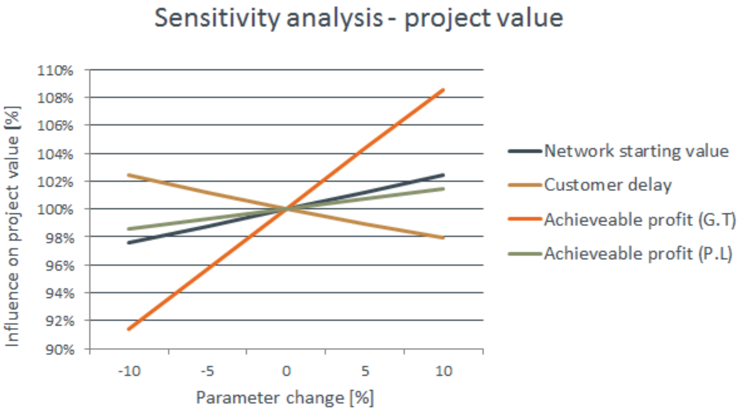


Figure 112: *Example project: Sensitivity analysis – Project value [own illustration]*

Parameter were changed by per cent value plotted on the x – axis, resulting changes in project value (after 15 years = program limit) were plotted as percentage on the y- axis

As can be seen the most important factor (of the investigated) is the achievable profit per MWh from geothermal well (G.T.). Values concerning speed of costumer acquisition also have a considerable impact. (Delay until end value is reached and starting value). In this example project peak load profits are at least important.

Please note, that lots of other influencing parameters had been mentioned before, but not all of them can be investigated by a spider chart so easily and general valid. Investigation of geographic circumstances or different well designs etc. does not make sense in a made up example, which does not mean that they would be minor important.

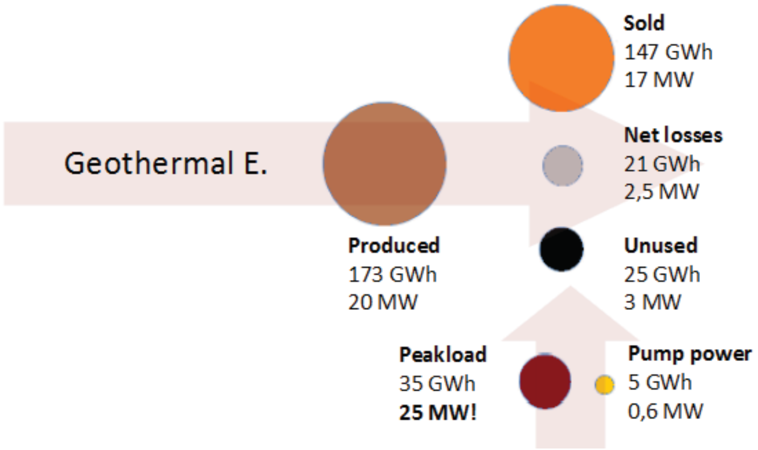


Figure 113: *Energy flux diagram [own illustration]*

Geothermal efficiency 72%; Total efficiency: 83 %; Energy supply by geothermal source: 80%, by peak load: 20 %, Power supply geothermal source: 42 %; Power supply peak load: 48 %

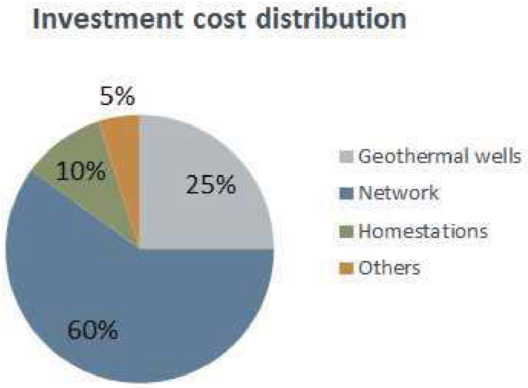


Figure 114: *Cost distribution of geothermal well for heating energy support [own illustration]*

The given percentages are a matter of magnitude.

Rough estimated investment costs

Extreme hard to predict as influenced by various project individual factors

Drilling (Injection + Production Well):	10 – 20Mio €
Network:	50 – 100 Mio €
Peak Load	5 – 20 Mio €
Others	5 Mio €
Total:	**70 – 145 Mio €***

*no investment support considered

Realistic geothermal large scale projects running over a project life time of 20 years can achieve internal rates of interests of 7-8 % at maximum, most likely below 5 %. Please note that the rough estimation mode does not take the delayed network investment costs into account, which would have a positive impact on the overall economics.

15.1.5 Conclusion – large scale geothermal heating supply projects

General

This project type requires relatively large amount of costumers, ideally base load demand from industry. (Towns with more than 10.000 – 15.000 inhabitants at least) achievable internal rate of return is quite low and long project life times are required. This is mainly due to time consumed for network build up and costumer connection behaviour.

For a private company these projects are most likely not very interesting. Communities have different evaluation criteria for energy supplying projects and might consider a geothermal heating supply due to ecological and community image reasons.

Potential

Very low, not many areas in the Molasse basin offer both: Fitting geology and costumer demand, and even if both are given achievable profits are as mentioned very low.

Challenges / Risks

Costumer acquisition, geological risk, drilling costs,

Perspectives

It is not realistic to expect investment cost reduction or heating energy price increase in a magnitude that boost this projects being economically interesting, in the next 10 years.

Only possibility would be governmental regulations, which enforces both: Reduction of network costs by applying new technical regulations (in other European countries e.g. Denmark heating network investment costs are only 33 – 50 % compared to Germany), and a connection enforcement for all potential costumer. None of these measurements is expected.

15.2 Geothermal electric power and heating energy production

15.2.1 Comment

Please note that the following project description is done in the rough estimation mode; it is not a case study. It is a try to visualise the characteristics of such a project. It was not target to try to demonstrate exact values, which also would not make sense in a made up example In this mode basically the achievable revenues (including most important operation costs) there origination and major influences on them are illustrated, investment costs which are strongly dependent on local circumstances are given as possible ranges.

15.2.2 Project set up

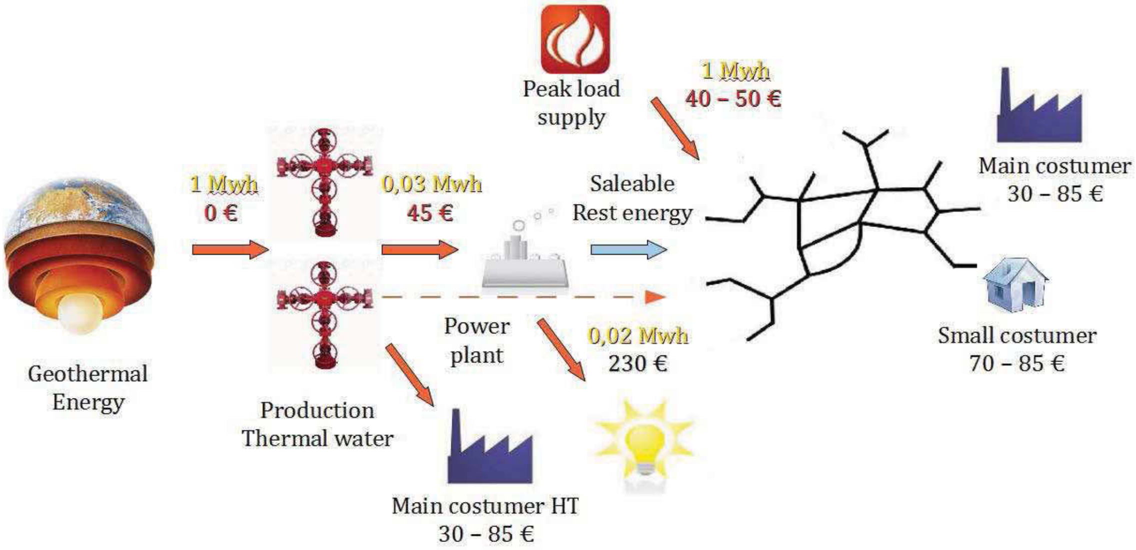
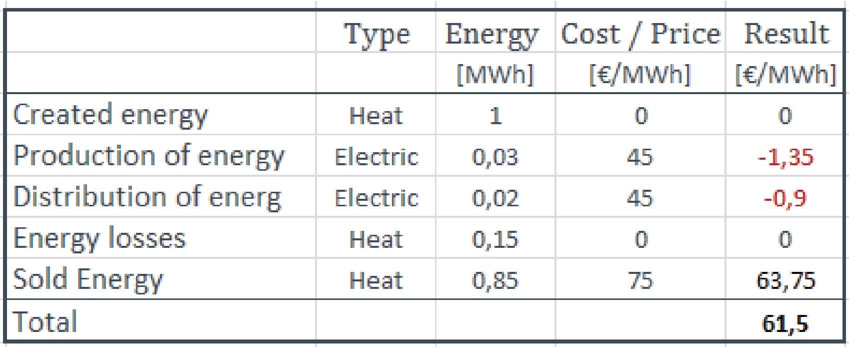
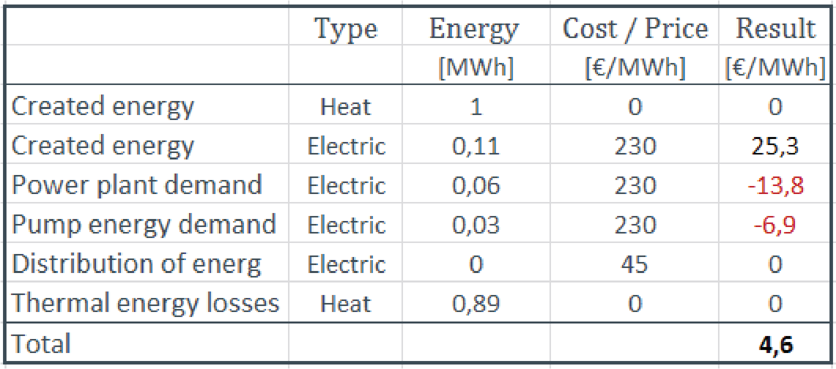


Figure 115: *Project set up: Geothermal electric power and heating energy production [own illustration]*



	Type	Energy	Cost / Price	Result
		[MWh]	[€/MWh]	[€/MWh]
Created energy	Heat	1	0	0
Production of energy	Electric	0,03	45	-1,35
Distribution of energ	Electric	0,02	45	-0,9
Energy losses	Heat	0,15	0	0
Sold Energy	Heat	0,85	75	63,75
Total				**61,5**

Figure 116: *Theoretical creation of value per produced MWh used as heating energy [own illustration]*



	Type	Energy [MWh]	Cost / Price [€/MWh]	Result [€/MWh]
Created energy	Heat	1	0	0
Created energy	Electric	0,11	230	25,3
Power plant demand	Electric	0,06	230	-13,8
Pump energy demand	Electric	0,03	230	-6,9
Distribution of energ	Electric	0	45	0
Thermal energy losses	Heat	0,89	0	0
Total				**4,6**

Figure 117: *Theoretical creation of value per produced MWh used in power plant [own illustration]. In reality the total creation of value is higher as electricity is bought at market prices (~45 €/MWh).*

Valid for an air cooled ORC power plant run with a forward flow temperature of 145°C

Note that the theoretical creation of value, per produced MWh, used in a heating network is approximately thirteen times higher in comparison of being used in a power plant. Only advantage of electricity production is, that no distribution network is required, (major investment costs) and due to the forced buy off full revenues start from the first day being online.

15.2.3 Most important influences on economics

For the sale of heating energy the same influences are valid, that was discussed previously. The additional electricity market is relatively simple. Basically there are three possible support levels:

Basis support:	160 €/MWh
Online before Dec. 2015	+ 40 €/MWh
Utilisation of heating energy	+ 30 €/MWh
Petro thermal technology	+ 40 €/MWh

Federal support in Germany (in Austria 72, 4 €/MWh}

For a geothermal project as described here, the petro thermal technology bonus is not achievable, as it is for projects which do not utilize thermal energy by producing reservoir water, but by heat energy stored in rocks. (E.g.: “Hot Dry Rock” wells)

The utilisation of heating energy bonus is given if, 20 % of the produced energy is used in a heating network. This definition seems to be quite clear; nevertheless there have been discussions how it shall be interpreted.

Do the 20 % refer to:

1.) The total amount of useable energy (From production to network backflow temperature)
2.) The amount of energy used in the power plant
3.) The amount of energy left after the power plant

In most cases the project owner does have a too small heating demand potential in the area, and tries to keep the hurdle as low as possible. Therefore juridical trickery is done to allow receiving the heating energy bonus at very low utilization levels. Normally definition number 2 is applied, with the argumentation that this would also be the energy to which the bonus is given. Also definition number 1 is not clearly defined as network backflow temperature is changed as described in chapter 7.3

15.2.4 Example: Geothermal electric power and heating energy production

Assumptions:

Electricity production

Power plant online before Dec 2015
20 % of total usable heating energy has to be (and is) utilized
Electricity price: 230 €/MWh (static)
Power plant type: ORC air cooled
Thermal efficiency: 11 %
Backflow temperature: 75°C
Own power demand: 60 % (of gross production)
Pump power demand: 1,2 MW

Demand structure

Small town with 4000 inhabitants and 5 MW industrial water demand.

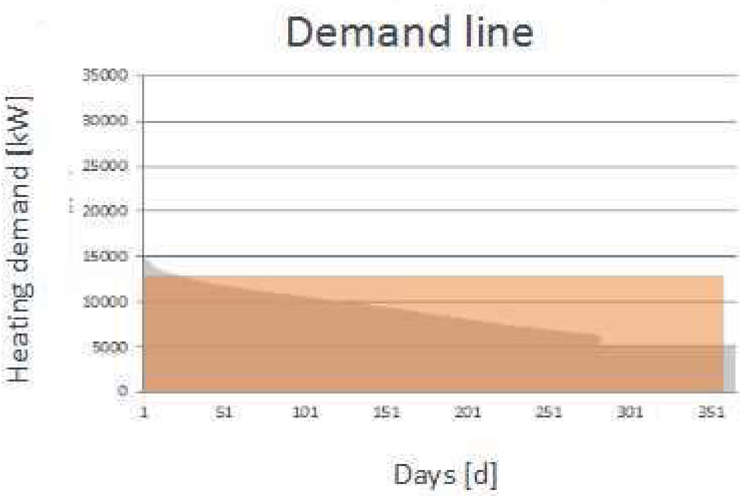


Figure 118: *Examples demand line [own illustration]*

Network

Forward / backward flow:	85/ 45 °C
Customer behaviour	(35/90/7log) [Start value/End value/Delay/Function]
Average achievable profit:	70 €/MWh (geothermal energy)
Average achievable profit:	35 €/MWh (peak load)

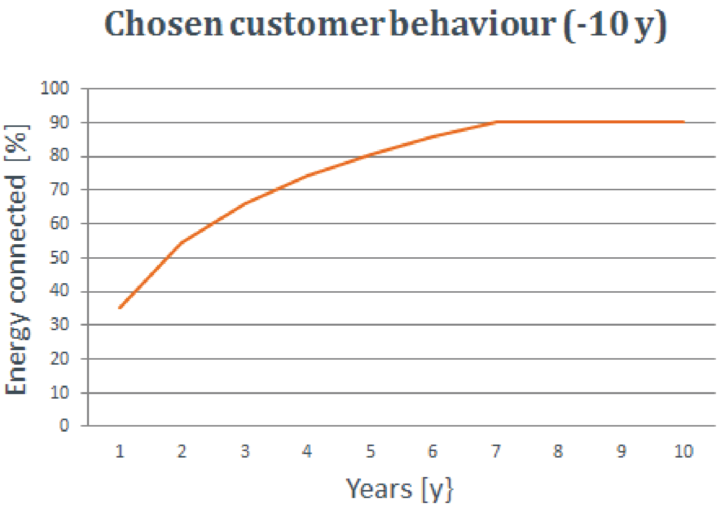


Figure 119: Examples customer behaviour [own illustration]

(Including delay due to network build up)

Wellbore

Produced energy:	43 MW
Temperature:	145 °C
TVD	4500 m
Production rate:	~120l/s
Casing schema	Standard 8 5/8” ending diameter

Economics

Anticipated internal rate of return:	7 %
Project life time	15 y

Operation costs

Power plants own electricity demand

Pumping power requirement

1, 5 % of built up network investment costs

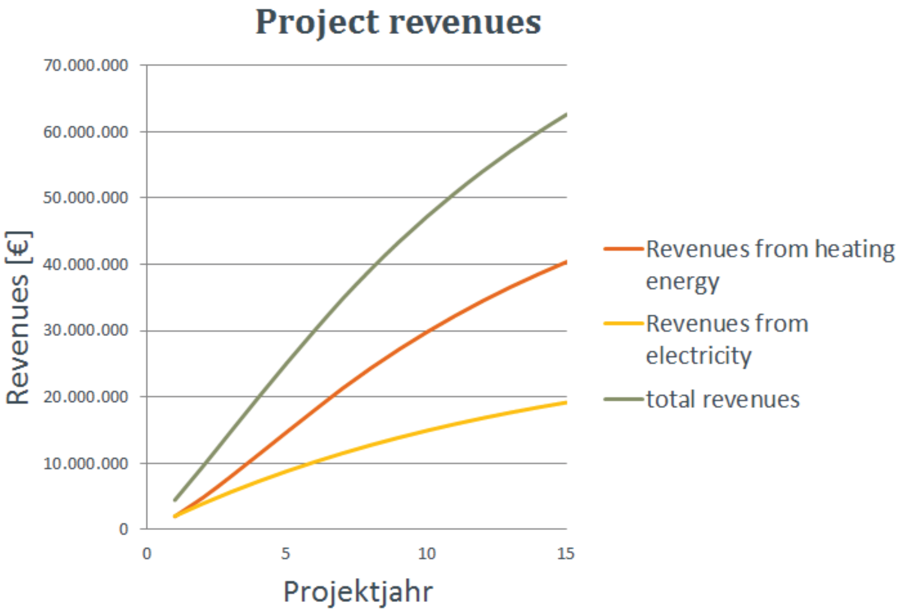


Figure 120: *Project revenues [own illustration]*

As illustrated still the heating energy revenues are more important than those earned from electricity sale, in the given example. (Again it is mentioned that usually the demand for the pumps and the power plant is bought at market prices and not taken from own production, as assumed in this example) However especially in the first project years revenues from electricity are considerable high, improving the economics of the total project. Please note that this project has a lifetime of 15 years, unlike the previous discussed. This is due to the fact that federal support ends after this time. Additionally federal support decreases by 2 per cent every year, which is neglected here. (Rough estimation mode)

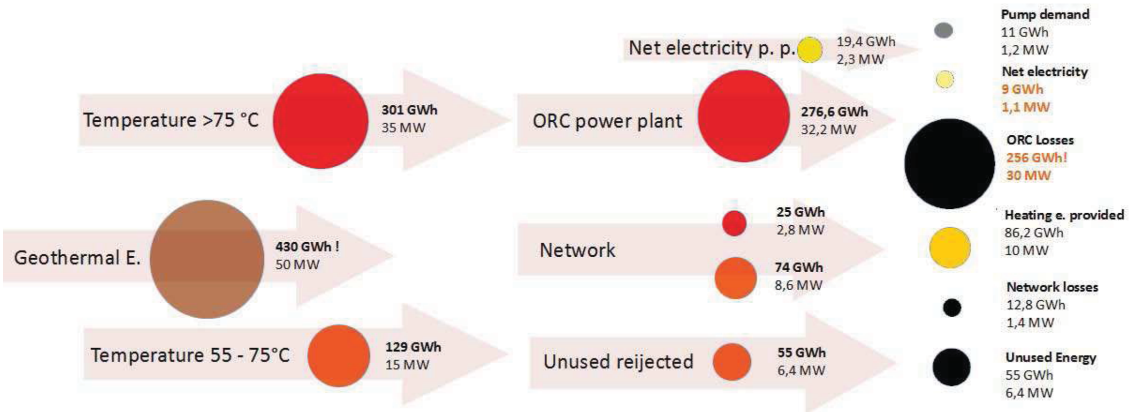


Figure 121:*Energy flux diagram [own illustration]*

(Please note that ORC losses revere to system losses and energy cooled down to an unusable Temperature level -> unusable = not usable for a standard heat distribution network)

Net electricity p. p. = Net electricity power plant

The produced heat energy flow is diverted in energy above 75°C (fitting for electricity production) and between 75 °C (backflow of power plant) and 55 °C (backflow of network). In the next step most of high quality energy is directed to the ORC power plant, a smaller portion is bypassed and mixtured with low quality energy to achieve the (absolute minimum) necessary network forward flow temperature of 85°C.

The high quality energy is turned to electric energy at an efficiency of 11%, 60% of it is demanded by the power plant itself, resulting in a power plant net efficiency of 5 %. (Optimistic) production pump demand is also subtracted, yielding a final efficiency of 2, 5% (network electric power demand is neglected)

The, by mentioned mixture, levelled up energy is directed to the network suffering 15% losses (2, 9 % of total energy). Remaining 85 % are sold to the costumer

Unused rest low temperature energy is re injected

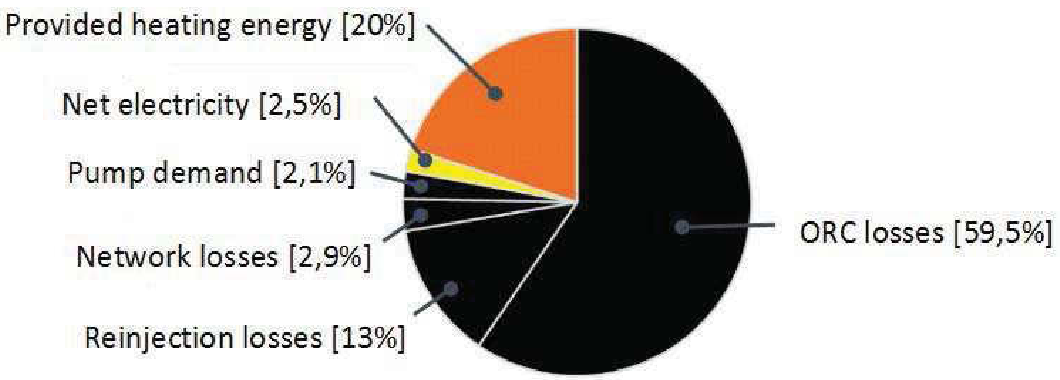


Figure 122: *Energy efficiency of example project [own illustration]*

In *Figure 121* and *Figure 122* the enormous waste of energy is illustrated. Please remember that in most projects juridical trickery is done to avoid such a high utilisation of heating energy. In other words, in most projects the total efficiency is even worse.

Please note that this project has a net electric power output of 1, 1 MW (buying electricity for its own heating network). For comparison an average modern fossil power plant has a net power of approximately 300 to 500 MW.

An average biomass CHP unit fed by a few farms has 0, 5 MW net electric output!

These projects have nothing to do with a responsible usage of existing resources!

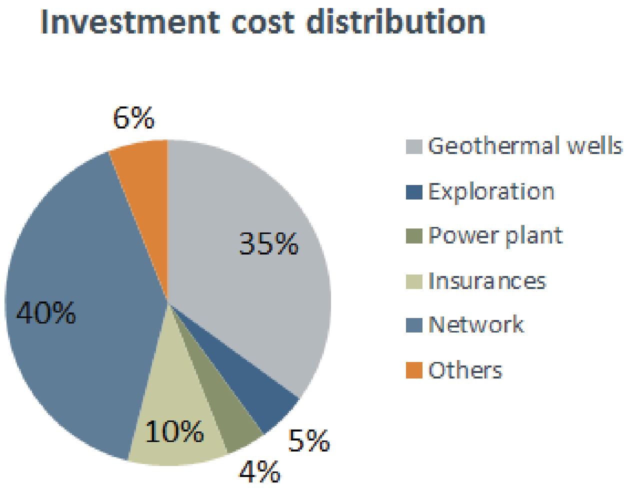


Figure 123: *Investment cost distribution [own illustration]*

Given values are matters of magnitude

Rough estimated investment costs

Drilling (Injection + Production Well):	15 – 25 Mio €
Exploration:	3 – 6 Mio €
Power plant:	2 – 4 Mio €
Insurances	5 – 10 Mio €
Network	20 - 30 Mio €
Others	5 Mio €
Total:	**50 – 80 Mio €**

*no investment support considered

Realistic achieve able internal rate of returns are below 7 or 8 % for a project life time of 15 years. Remark able is, that these projects still seems to be more profitable than single heating demand supply.

These slight advantages however have some serious drawbacks, for example: High risk connected to drilling costs, Risk of early re injected water break through or depletion of reservoir, due to enormous production.

15.2.5 Conclusion –electric power and heating energy production

General

This project types requires at least a town with approximately 5000 inhabitants and industrial demand, or a city with approximately 15000 inhabitants without industrial main costumers. (Assuming that a majority of the “waste” heat energy after electricity production shall be utilized)

As in the heating supply project the achievable rates of return are relatively low, but slightly higher. This is mainly due to the immediate revenues originating from electric power supply, which do not require network investment costs. The slightly better economics are bought by higher risk concerning geology and drilling costs.

The net efficiencies are very low and without enormous support (Energy price, Investment support, cheap credits and insurances) these projects would never be economic, and are not even though most times.

The enormous waste of energy in the thermodynamic process does not fit to the ecological background and a reasonable usage of given resources the support is given for

Potential

Very low as there are little fitting locations. The electric power production shifts the local requirements from heat energy demand to geological needs (Less heating energy demand, however higher temperature and achievable production rate are required)

Challenges / Risks

Drilling Costs, Geological risk, Exploration, Costumer acquisition

Perspectives

Generally spoken: Electric energy from geothermal sources is not economic or technically reasonable, now or in conceivable future. (In the area)

Of course there are exceptions, for example if there is already an existing heat distribution network or local geological circumstances etc.

15.3 Support of fossil power plants with geothermal energy

15.3.1 Comment

Please note that the following project description is a suggestion of the author. It is not proved, that a setup like this will work at all nor be economical. The suggestion will further be investigated.

As discussed in: "Geothermal energy usage in classic fossil power plants" (and previous chapters) the preheating of feed water is done by bypassing hot steam before the turbines to heat up the feeding water before being heated up in the boiler.

This bypassed steam could stay at least partial in the turbines if the preheating would be done by geothermal energy at least to some extent.

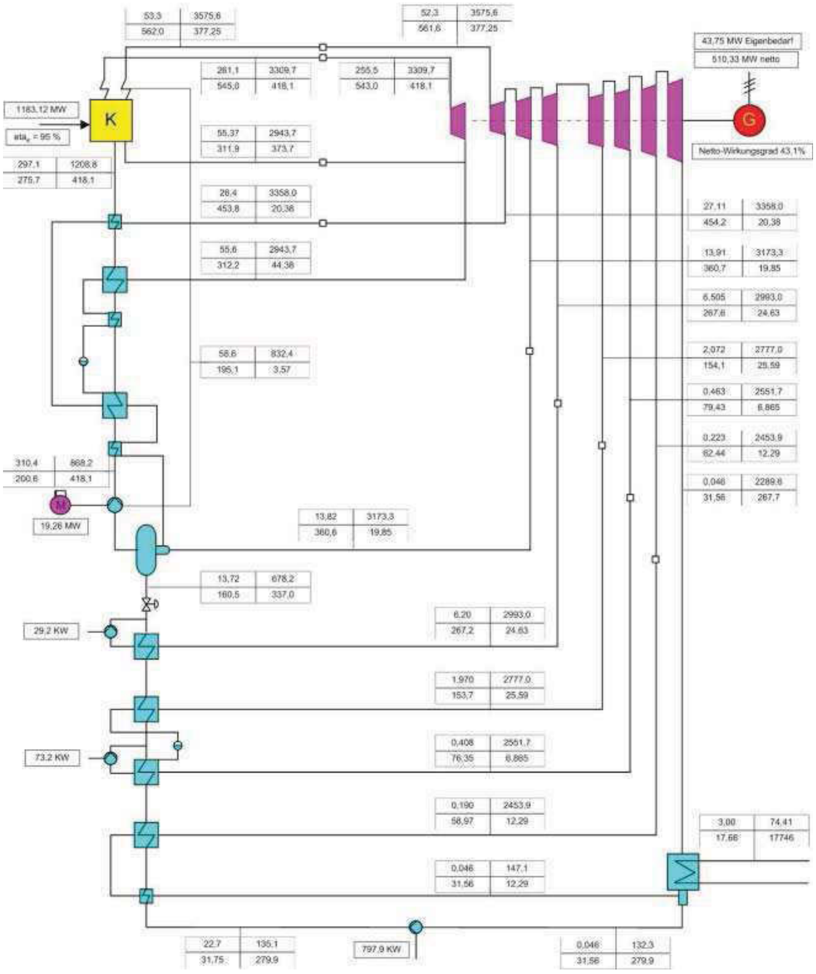


Figure 124: Schema of the steam power plant block 4 "Staudinger" [14]

Physical state of feed water described in boxes separated in four quarters, from the upper left quarter clockwise: Pressure [bar]; Enthalpy [kJ/kg]; Mass flow [kg/s]; Temperature [°C]

As can be seen in the power plant schema preheating energy is used at temperature levels of 360 – 31 °C (before being vaporised), so at least partially in the range of geothermal energy.

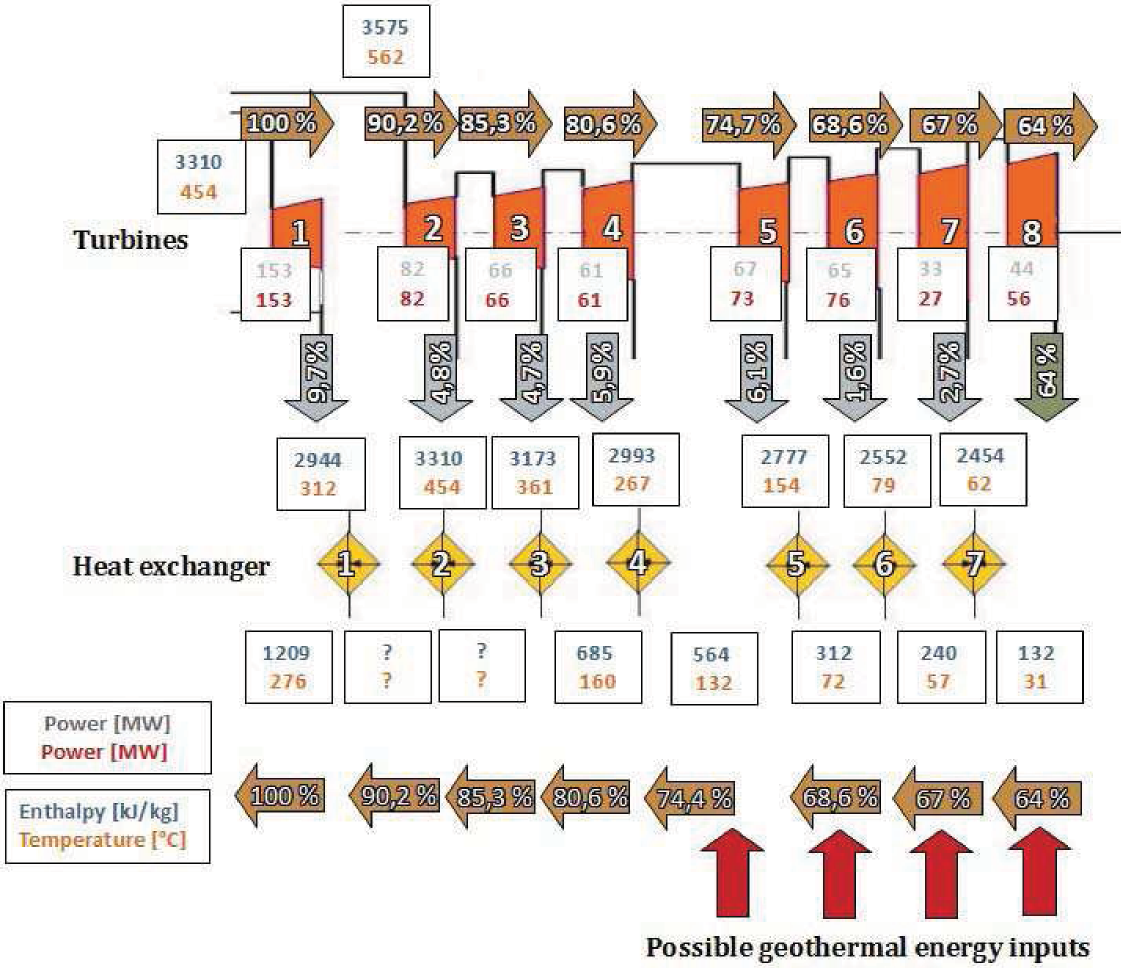


Figure 125:
Simplified schema of the Staudinger fossil power plant [own illustration according to 14]

As can be seen steam bypassed from the turbines has a very high enthalpy, therefor only relatively low amounts of the total mass flow needs to be taken (1,6 % to 9,7% per stage) nevertheless summing up to leaving only 64 % of the total flow in stage number 8. Geothermal energy might be used in the heat exchangers 3 to 7, but large mass flows will be necessary as the geothermal energy has much lower enthalpy as the power plant steam at the same temperature level (Water not steam produced).

Please note that following data was not calculated in an iterative process as necessary but quick estimated. As described for one turbine in the following.

$$P_{BP} = (h_{BP} - h_{HEO}) * m_{BP}$$

Equation 26: *Bypassed feed water preheating energy*

Power bypassed from turbine used in the heat exchanger for preheating

P_{BP} = Bypassed power [kW]; h_{BP} = Enthalpy of bypassed steam [kJ/kg];h_{HEO} = Enthalpy of heat exchanger output [kJ/kg]; m_{BP} = bypassed mass flow [kg/s]

$$P_{GTS} = [(h_{GT} - (h_{HEO} + 5°C)] * m_{GT}$$

***Equation 27:** Energy supported from geothermal source*

Power originating from geothermal source used in heat exchanger to save bypassed energy from turbine

P_{GTS} = Power from geothermal source [kW]; h_{GT} = Enthalpy of geothermal water [kJ/kg]; m_{GT} = mass flow geothermal source [kg/s]

$$m_s = \frac{E_{GPS}}{E_{PP}} * m_{BP}$$

***Equation 28:** Resulting saved mass flow in turbine*

m_{S}= Substituted mass flow in turbine

$$P_{AD} = (h_{BP} - \ h_{LS}) * m_{BP}$$

***Equation 29:** Additional created energy*

P_{AD} = additional created gross power [kW]; hLS = Enthalpy on the power plants “low side” (= after last turbine before condenser) [kJ/kg]

$$P_{ADnet} = \acute{\eta}_{Turbin} * \acute{\eta}_{Generator} * \acute{\eta}_{Additional\ massflow} * \ P_{AD}$$

***Equation 30**: Additional created net energy*

Additional created mass flow refers to the additional mass flow occurring at the “low side” of the power plant due to savings in steam bypass. This additional mass flow also needs to be preheated by the geothermal source. Correct calculation would need an iterative process, here in this estimation it is considered by an average efficiency value.

P_{ADnet} = Additional created net power [kW]; ή = Efficiency []

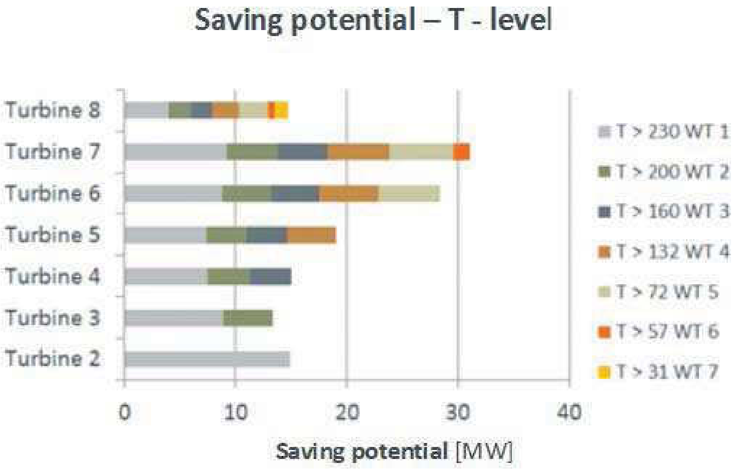


Figure 126: *Saving potential for different temperature levels per turbine [own illustration]*

Steam substituted in Turbine 2 will also perform mechanical work in the turbines 3 – 8. The higher the geothermal energy input the higher the saving potential.

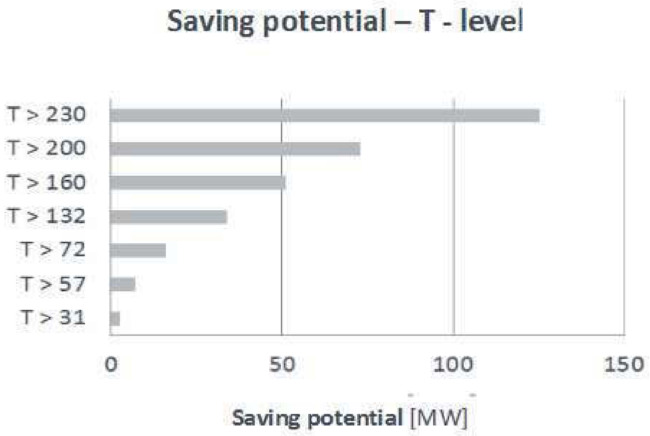


Figure 127*: Saving potential for different temperature levels [own illustration]*

Assumed is a complete substitution of bypassed energy by geothermal sources. If this could be done at a level of 160°C approximately 75 MW could be produced additionally. At a level of 57 °C still approximately 8 MW.

Example:

Geothermal sources used in a fossil power plant compared to ORC power plant. Energy is only used for power plant supply. Therefor the energy price is 200 €/MWh.

<u>Geothermal source 1</u>

Temperature:	175 °C
Production rate:	120 l/s
Pump demand:	1000 kW

Geothermal source 2
Temperature: 135 °C
Production rate: 120 l/s
Pump demand: 750 kW

Geothermal source 3
Temperature: 100 °C
Production rate: 120 l/s
Pump demand: 500 kW

Net electric efficiencies of ORC power plant were chosen according to chapter: 13.9.3 Comparison of both power plant types. System losses in fossil power plant: Heat exchanger according to “***Figure 128:*** *Temperature levels at heat exchanger (for geothermal source 1)*”; mechanical losses in turbines: 2%; mechanical losses in generator 2%, created additional mass flow: 5%

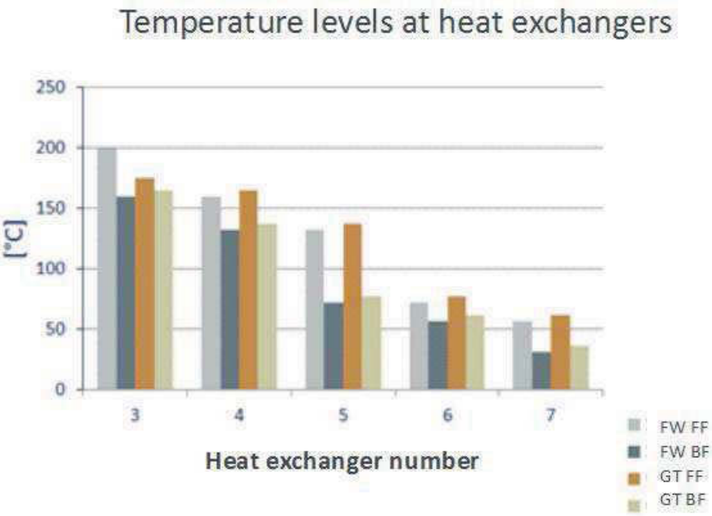


Figure 128: *Temperature levels at heat exchanger (for geothermal source 1) [own illustration]*

FW FF = Feed water forward flow; FW BF Feed water backflow; GT FF = Geothermal forward flow; GT BF = Geothermal backflow

It is assumed that the forward and backward flow of the geothermal energy has to be 5 °C higher than the feed water to allow heat transfer in a reasonable time.

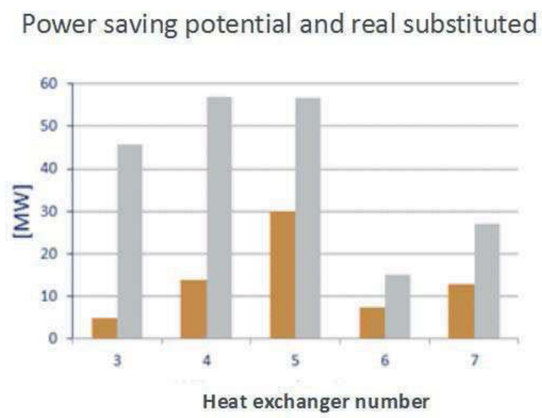


Figure 129: *Thermal power of bypassed steam (grey) and geothermal energy substitute (brown) [own illustration]*

Approximately a 25 to 50 % of the bypassed steam can be substituted by geothermal energy

	Utilized Power	Gross Electricity	Net Electricity	System efficiency	Procet value Electricity
	[MW]	[MW]	[MW]	[]	[€]
ORC	52	7	2,6	5,0	39.000.000
FPP c..e.GTE	70	15	13,0	18,6	197.000.000
Improvement [%]	135	300	500	380	300

Figure 130: *Results geothermal source 1 [own illustration]*

	Utilized Power	Gross Electricity	Net Electricity	System efficiency	Procet value Electricity
	[MW]	[MW]	[MW]	[]	[€]
ORC	32	3	1,1	3,4	17.000.000
FPP c..e.GTE	50	8	7,1	14,6	108.000.000
Improvement [%]	150	340	660	425	660

Figure 131:*Results geothermal source 2 [own illustration]*

	Utilized Power	Gross Electricity	Net Electricity	System efficiency	Procet value Electricity
	[MW]	[MW]	[MW]	[]	[€]
ORC	15	1	-	0	0
FPP c..e.GTE	32	5	4,0	12,2	6.100.000
Improvement [%]	213	336	664	-	-

Figure 132: *Results geothermal source 3 [own illustration]*

FPP c.e. GTE = Fossil power plant supported by geothermal energy

Project value= Project life time: 15 years; Internal rate of return i: 7 %; Operation costs: pump and power plants own electricity demand.

As illustrated more geothermal energy can be utilised in the fossil power plant, due to being processed to deeper temperature levels. The pessimistic calculated gross and net electricity output of the geothermal supported fossil power plant, outnumbers those of the ORC power plant by far in all cases. Due to the high federal support of electric energy produced from geothermal sources (without usage of heating energy still 200 €/MWh), it seems very likely that those project might be economical interesting. However my technical background as a drilling engineer does not allow me to predict feasibility nor required investment costs.

15.3.2 Conclusion – Support of fossil power plant with geothermal energy

General

This project type has very high requirements on the location; a large fossil power plant is required near a fitting geothermal source. Nevertheless due to the very high achieve able revenues these project type might be interesting.

Potential

There are a few theoretically possible locations in Germany

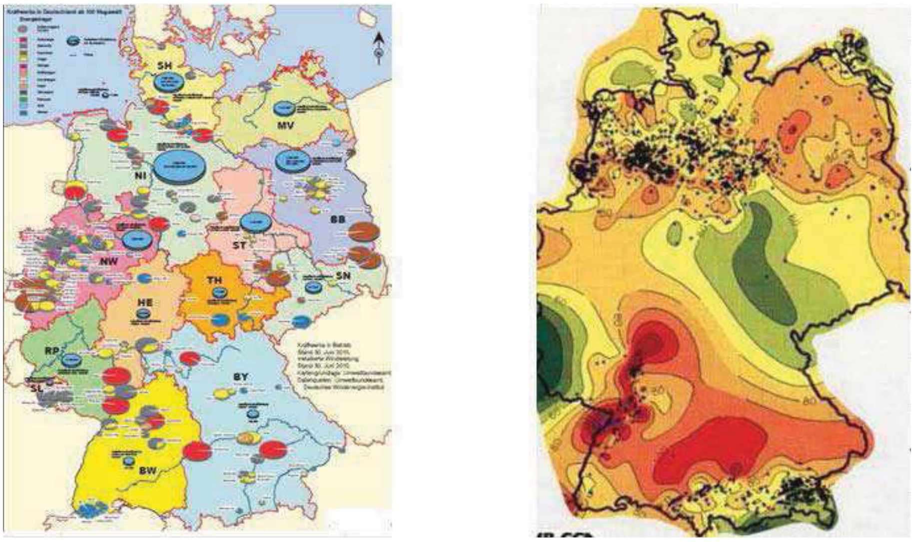


Figure 133: Fossil power plant support potential in Germany [own illustration]

Black, Brown and yellow circles refer to fossil power plants. Red circles refer to nuclear power plants, which utilize a compare able process concerning feed water preheating.

Challenges / Risks

Unknown application; drilling costs

16 Geothermal heat storage

16.1 Applications

1.) Solar Energy
2.) Combined Heat and Power Unit
    a. Biogas
    b. Other than biogas
3.) Regaining of industrial waste

16.2 Sediments ability to store heat

The major important physical property describing the ability of sediment to store heat is the total heat capacity of pore water and rock.

$$VHC_{total} = \varphi * MHC_{water} * \rho_{water} + (1-\varphi) * MHC_{rock} * \rho_{rock}$$

Equation 31: *Total heat capacity of sediments*

*VHC = Volume heat capacity [J/m³*K]; MHC = Mass heat capacity [J/kg*K]; ρ = Density [kg/m³]; φ= Porosity []*

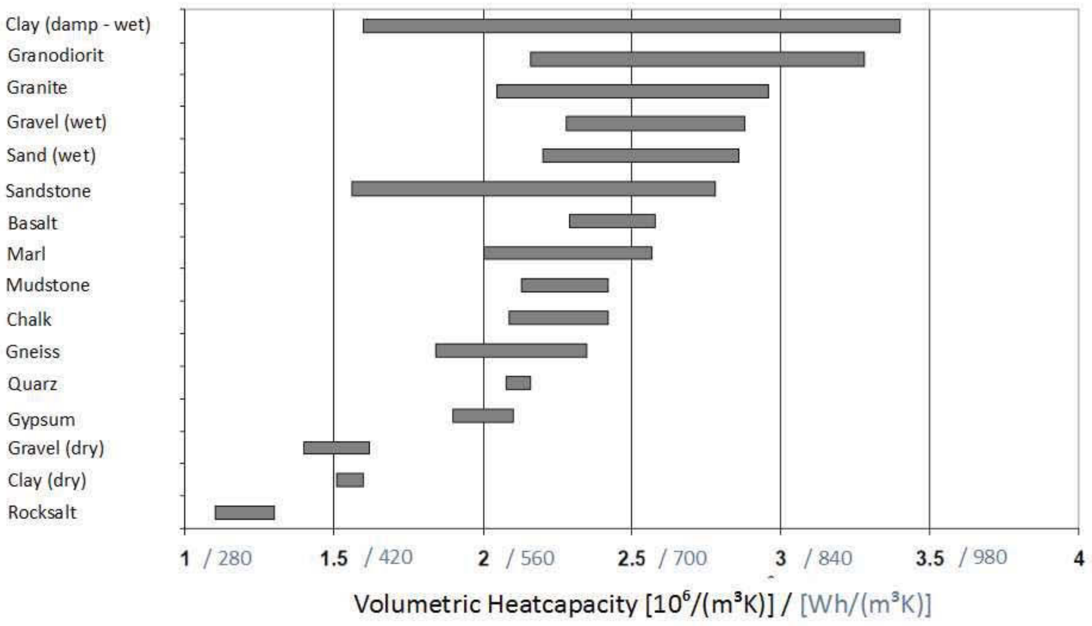


Figure 134 *Volumetric feat capacity of various rock types. (Range is mainly due to water content) [modified 18]*

$$SE_{total} = VHC * V_{Storage} * \Delta T$$

***Equation 32:** Total storable energy*

SE = Storable Energy [Wh]; VHC = Volume heat capacity [Wh/m³]; ΔT = Temperature difference [°K] (Between stored energy and heating network backflow temperature = usable temperature difference;

In other words the heat storing capacity depends on:

1.) Size of the storage
2.) Usable temperature difference
3.) Physical properties of sediments (mainly water content)

Please note the importance of storage temperature and low backflow temperature to necessary storage size.

Example

300 MWh shall be stored in typical sediment (700 Wh/(m³K))

Case 1:

Storage temperature:	85 °C
Network backflow temperature:	30 °C
Useable temperature difference	55 °C
Required volume:	**7.800 m³**

Case 2:

Storage temperature:	60 °C
Backflow temperature	30°C
Usable temperature difference	30 °C
Required volume:	14.300 m³

16.3 Principal underground storage types

1.) Aquifer Thermal Energy Storage (ATES)
2.) Borehole Thermal Energy Storage (BTES)
3.) Hybrid Systems

16.3.1 Aquifer storage systems

Aquifer storage systems are developed by wellbores connecting subsurface water containing sequences. Water is pumped via the “cold well” to the surface, heated up and reinjected through the “hot well”. The charging process is inverted to utilize the stored heat energy.

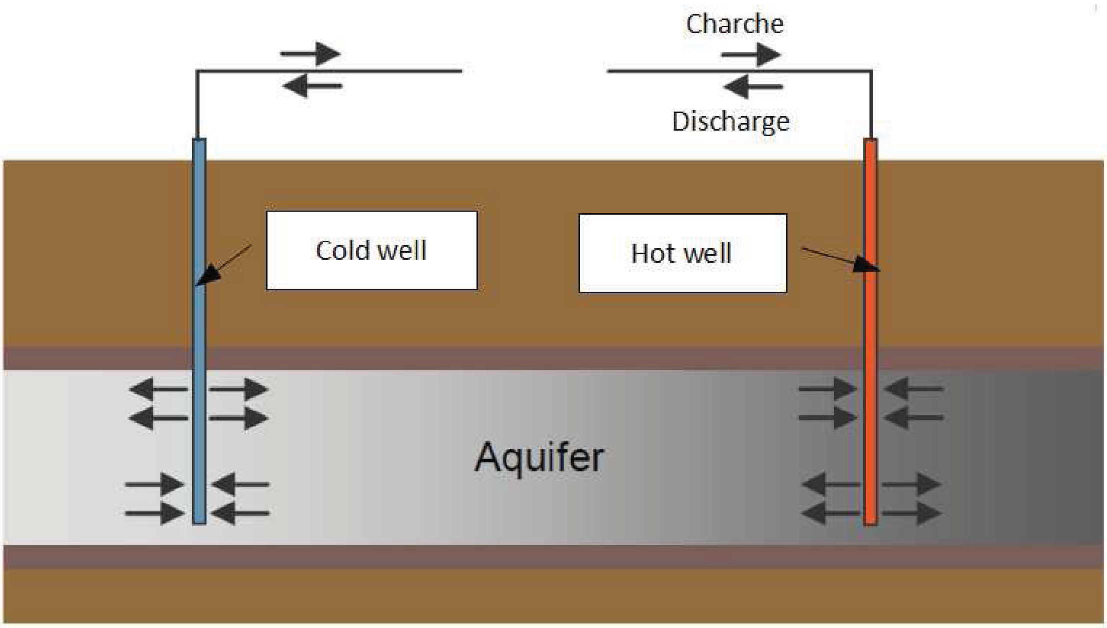


Figure 135:*Schema of an aquifer storage*

These storage systems contain volumes of at least 10.000 m³ and supply at least larger settlements. The first storage systems of this type where implemented 1996 and still work reliable. The investment costs are low compare to other storage systems.

There are several hundreds of these systems in operation, with the Netherlands and Sweden. Practically all systems are designed for low temperature applications (applying heat pumps) where both heat and cold are seasonally stored. [16]

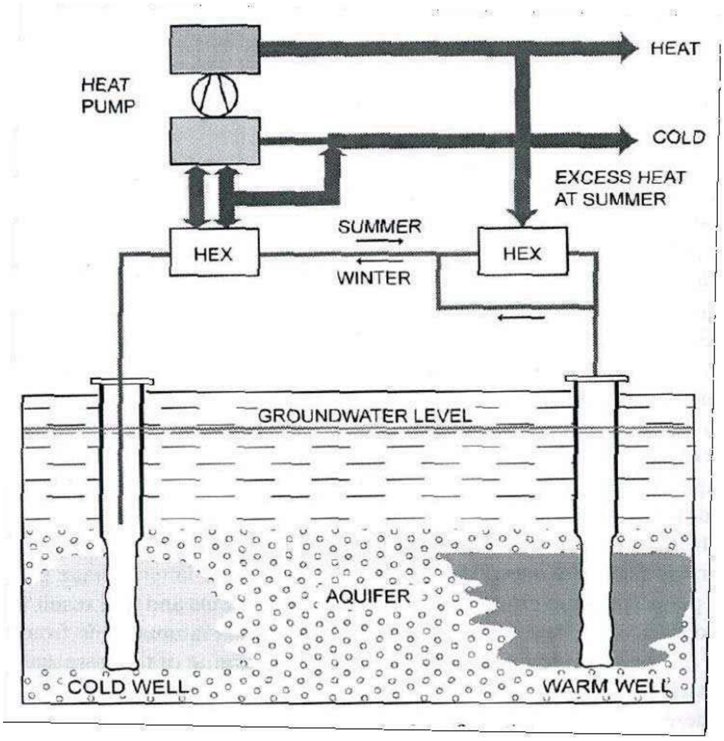


Figure 136 *Typical ATES setup in the Netherlands for low temperature application (Heat pump supported) [16]*

Heat and Cold from ambient air is stored at levels of approx. +5 °C (winter) and + 15°C (summer). Optional this can be used directly for preheating or cooling, or (more common) via a heat pump.

However there are systems applied for direct heating or short term storage.

In this case charging normally is done at a maximum Temperature level of about 75 °C (At Temperature levels of more than approx. 50°C chemical problems are likely to occur. Recharging is done Temperature levels from about 65 – 30 °C

ATES systems have relatively high requirements on the geology. The most important factors are:

1.) Groundwater table gradient (natural flow velocity)
2.) Geometry (Surface Area vs. thickness)
3.) Stratigraphy
4.) Static head
5.) Hydraulic conductivity
6.) Transmissivity
7.) Storage coefficient
8.) Leakage factor (Vertical leakage)
9.) Boundary conditions
10.) Groundwater chemistry [16]

For detail information original literature [16] (Olof Anderson Aquifer Thermal Energy Storage) is recommend.

16.3.2 Borehole thermal energy storage (BTES)

BTES consist of a number of closely spaced (1 -3, 5 m) boreholes, normally 50 – 200 m deep. These are serving as heat exchangers in the underground. For this reason they are equipped with Borehole Heat Exchangers, typically a single U – pipe. (Also double u pipes and coaxial pipes are in use). [16]

In the heat exchanger a heat (or cold) carrier is circulated to store or discharge thermal energy into or out of the underground. The storing process is mainly conductive and the temperature change of the rock will be restricted to only a few meters around each boreholes. [16].

These systems have been implemented in many countries with thousands of systems in operation. The numbers of plants are steadily growing and new countries are gradually starting to use these systems. They are typically applied for combined heating and cooling, normally supported with heat pumps for a better usage of the low temperature heat from the storage.

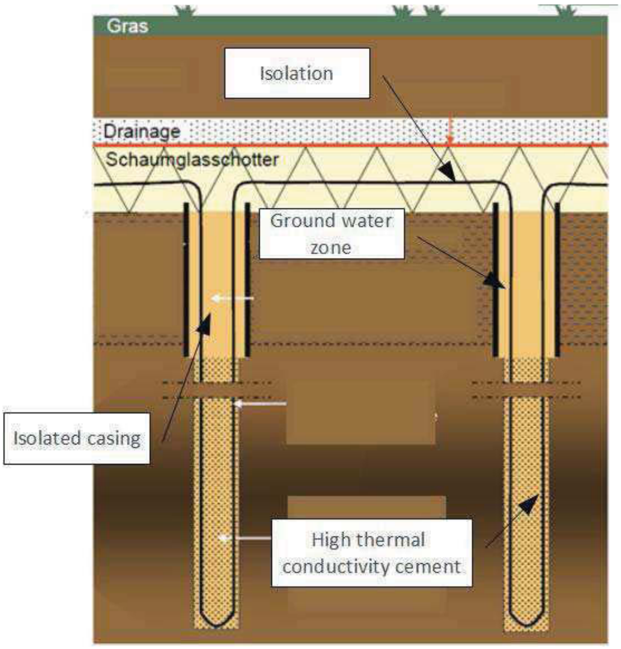


Figure 137 *Sketch of a borehole and heat exchanger component of a storage system*

Comparison to ATES

Compared to ATES these systems have the advantage, that there are lower requirements on the geology, and there is no direct contact with the groundwater, which avoids chemical problems. Additionally higher Temperatures can be stored and efficiency is usually better.

Drawbacks are the higher investment price, and lower deliverable power.

For detail information original literature [18] (Hans-Peter Ebert, Optimierung von Erdwärmesonden) is recommend.

16.4 Thermal storage systems in combination with solar energy

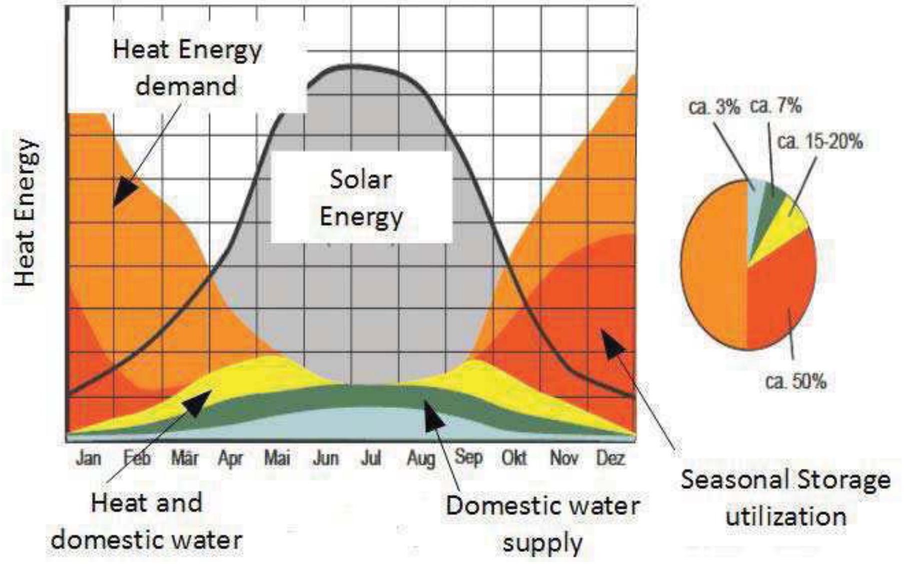


Figure 138 *Heat energy demand and solar irradiation.*

Illustrated is the amount of solar energy that can be utilized in a modern single family home with different systems. Systems that cover only domestic water demand – 7 %- Combination facilities 15 – 20 %. Systems including seasonal storage ~ 50 %.

Please notice that the storage system is discharged as early as possible to keep energy losses low.

As illustrated in Figure 138, the implementation of a seasonal storage system in a solar energy supply system can increase the solar cover ratio. From max. 20% to more than 50 %.

There have been numerous demonstration projects in Germany and other countries, some of them have been published, therefore the evaluation will not be done with the software, but some examples will be presented.

16.4.1 Solar district heating with seasonal aquifer storage system - Rostock

The following is a brief summary of the solar district heating pilot project in Rostock 2004

Summary

In May 2000 the solar supported district heating utilizing an ATES storage system went online. 108 Flats with a total living area of 7000 m² take 50% of their heating energy from 980 m² solar panels. The system is one out of eight demonstration projects that were done in the years 1994 – 2004.

Figure 139 *Rostock Brinckmannshöhe [19]*

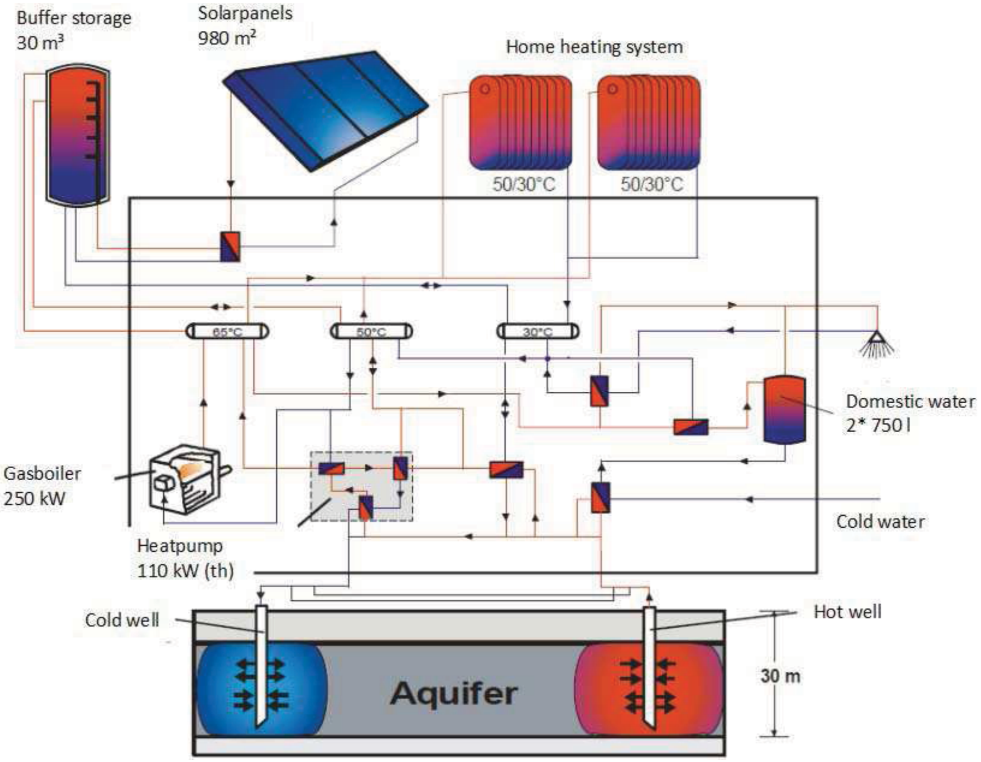


Figure 140 *Hydraulic scheme [modified 19]*

As can be seen the piping is done as a four pipe system, the domestic water preparation is supported by two buffer tanks (a 750 l) at a Temperature level of 65°C. The low heating system runs at F/B flow temperature of 50/30°C. (Please note the very low backward flow temperature, which is as mentioned vital to these kind of projects.

The Aquifer Storage is charged in summer out of the buffer storage if more solar energy is available than can be used in domestic water demand. The discharging is done via a heat exchanger as long as the hot wells temperature is high enough. Is this not the case a heat pump is used for levelling up the Temperature, up stream.

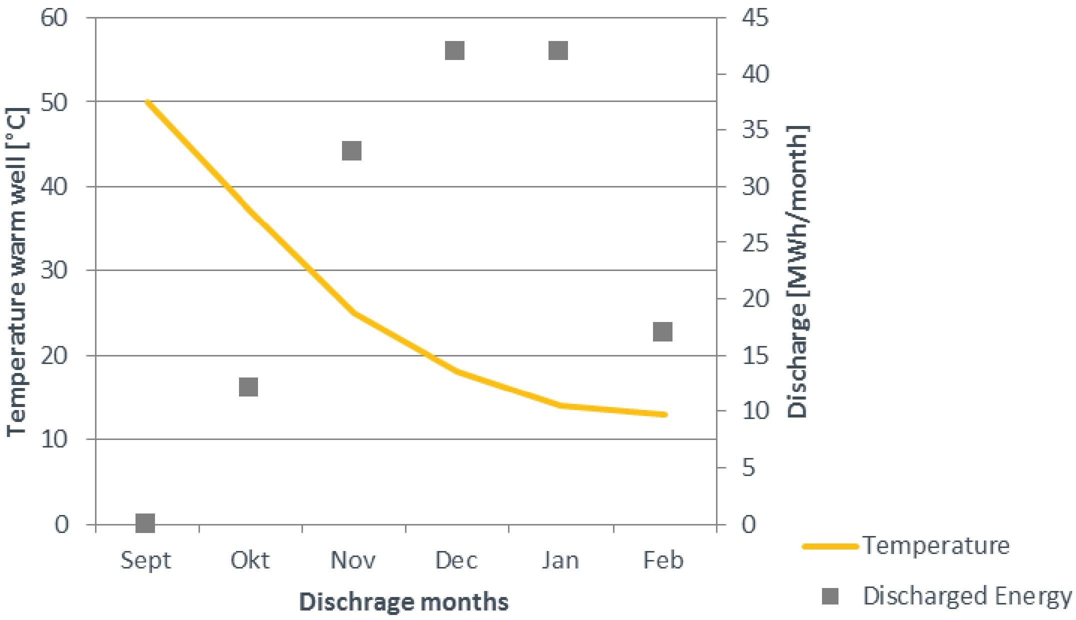


Figure 141 *Temperature development during discharging [own illustration according to 19]*

Temperature drops rapidly as soon as discharging starts; therefore support of heat pump becomes necessary very soon.

Aquifer storage system

The technical feasibility was confirmed by a pre investigation. In shallow depth (15-30 m) an Aquifer with low groundwater movements, bordered by impermeable layers to the top and the bottom. The Aquifer is connected to the surface via two wells (Injection and production well)

Energy utilization

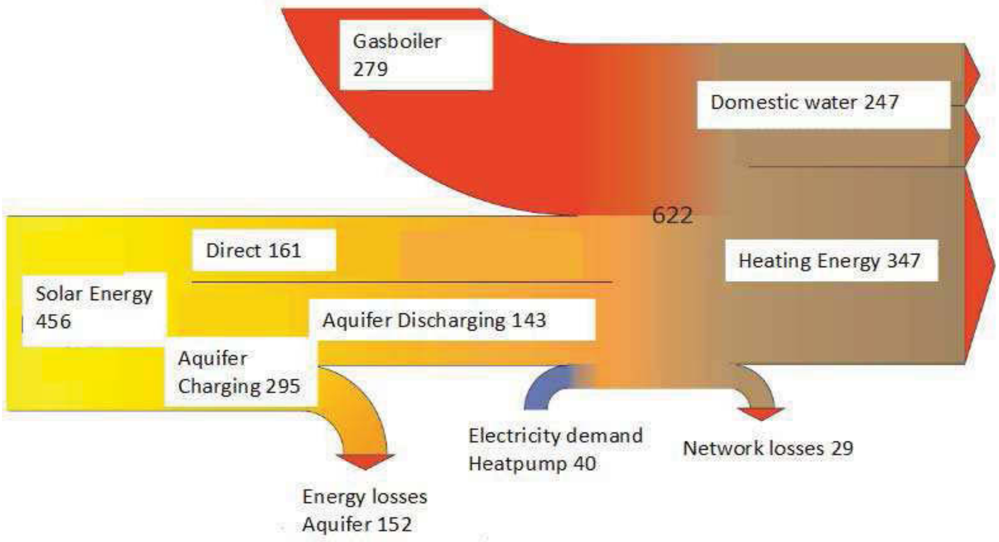
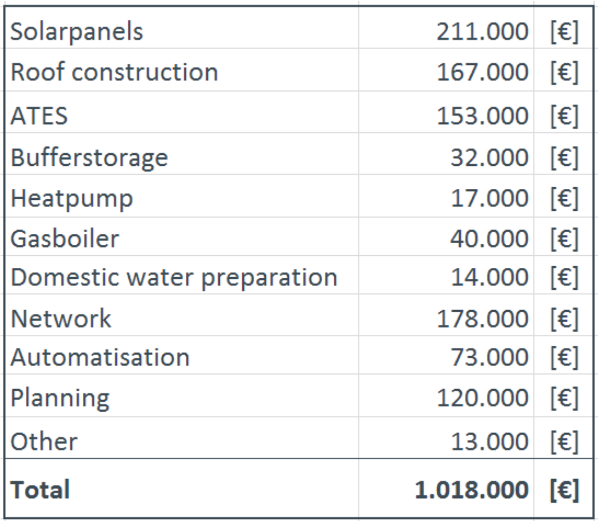


Figure 142 Energy flux diagram (Values in [MWh] [19]

The amount of solar energy is approximately 50 %, without a seasonal storage system usually only 10 % - 15 % can be achieved (Buffer storage systems). The rather high Energy losses in the Aquifer storage system (more than 50 %) are due to unexpected permeability inhomogeneity. [19]. Usually efficiencies of about 60% have been achieved in compare able systems.

Project costs



Solarpanels	211.000	[€]
Roof construction	167.000	[€]
ATES	153.000	[€]
Bufferstorage	32.000	[€]
Heatpump	17.000	[€]
Gasboiler	40.000	[€]
Domestic water preparation	14.000	[€]
Network	178.000	[€]
Automatisation	73.000	[€]
Planning	120.000	[€]
Other	13.000	[€]
Total	**1.018.000**	**[€]**

Figure 143 Investment Costs of total project [according to 19]

Assuming a life time of 40 years for the storage system and 20 years for the solar panels, yields a heat energy price of 260 €/MWh. (According to “VDI Richtlinie 2067, internal rate of return = 6%). For comparison a gas heating system would yield about 70 – 120 €/MWh.

16.4.2 Solar district heating with BTES seasonal storage system - Attenkirchen

The following is a brief summary of "Solare Nahwärme Attenkirchen – Erfahrungen beim Bau und Betrieb" [M.Reuß et al.]

Summary

The Solar district heating system in Attenkirchen supports 20 single-family homes 5 Double homes a tennis and a sports hall with heating and domestic water energy, by utilizing a combination of a tank and a BTES storage system.

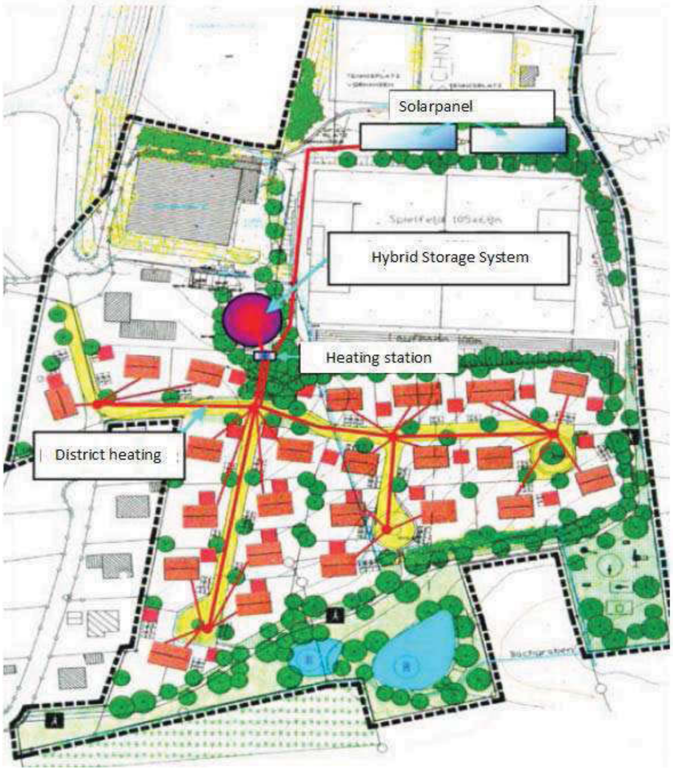


Figure 144 *"Overview district heating system Attenkirchen" [21]*

Figure 143 illustrates the district heating system and its components. The buildings are very well heat insulated and equipped with a low Temperature heating system which allows backflow Temperatures down to 24 °C. Additionally a buffer storage and automatized charging system was developed to allow an alternating domestic water support with 65 °C to keep network temperatures low most of the time. [According to 21]

Heating demand is about 385 MWh/a and domestic water demand approximately 102 MWh/a. Target was to achieve a solar energy utilisation of more than 50 %. [According to 21]

Storage system

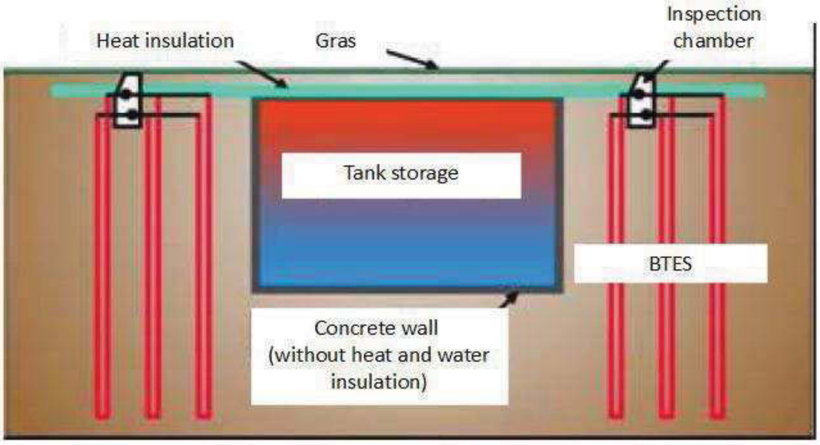


Figure 145 "Hybrid Storage System utilized in Attenkirchen" [21]

The Hybrid Storage System in Attenkirchen consists of a Tank storage system (500 [m^3 WE*]) surrounded by a BTES Storage (6800 [m^3WE]), were the Borehole heat exchangers are situated in three rings around the Tank.

The Tank is used as a buffer storage system; it does not need to be insulated (except to the surface) as heat losses to the side and to some amount also to the bottom can be regained in the BTES. The storage offers high power due to its large buffer storage, good efficiency and low costs due to the relatively cheap BTES system.

*WE = Water Equivalent.

Energy utilisation

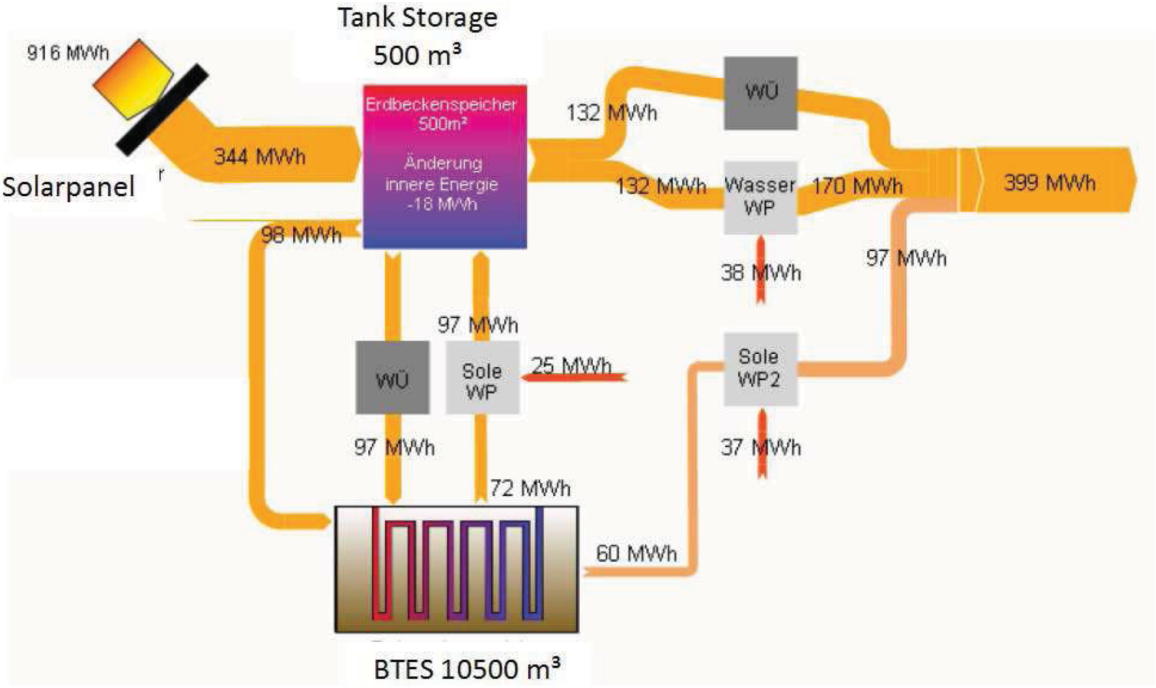


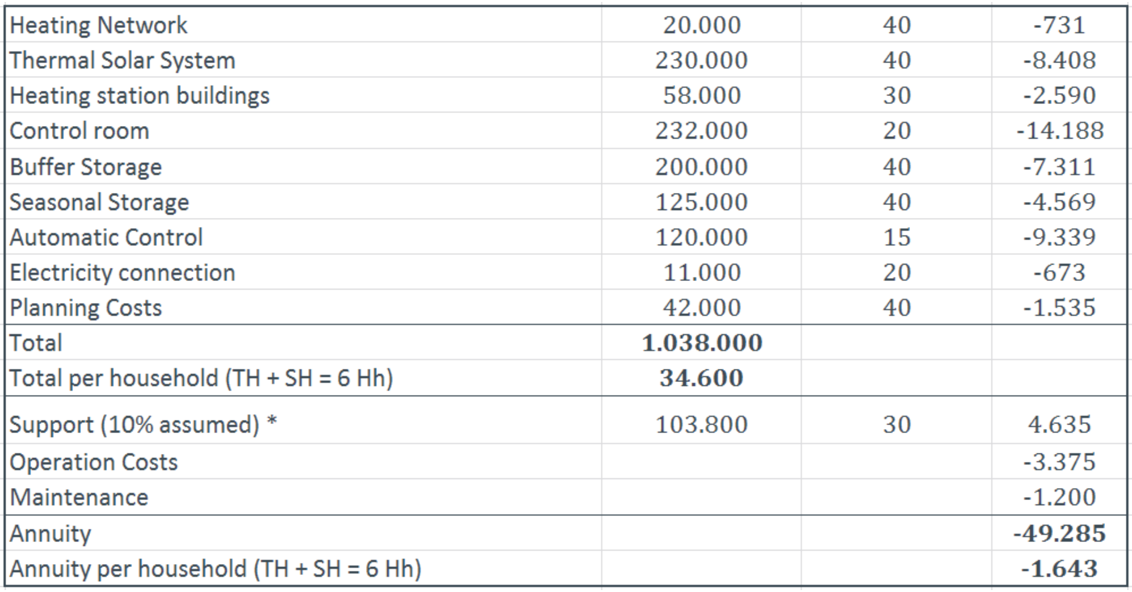
Figure 146 "Energy flow diagram Attenkirchen" [21]

As illustrated in Figure 145 in summer the solar energy is directed to the buffer storage, from there it is used to charge the BTES system, via a heat exchanger or simply be heat transfer from the tank to the surrounding sediments.

In winter the BTES system is used to charge the Buffer Storage via a heat pump and directly feeds the district heating system (also via a heat pump).

The system can cover its demand with solar energy to 74%.

Investment costs



Heating Network	20.000	40	-731
Thermal Solar System	230.000	40	-8.408
Heating station buildings	58.000	30	-2.590
Control room	232.000	20	-14.188
Buffer Storage	200.000	40	-7.311
Seasonal Storage	125.000	40	-4.569
Automatic Control	120.000	15	-9.339
Electricity connection	11.000	20	-673
Planning Costs	42.000	40	-1.535
Total	**1.038.000**		
Total per household (TH + SH = 6 Hh)	**34.600**		
Support (10% assumed) *	103.800	30	4.635
Operation Costs			-3.375
Maintenance			-1.200
Annuity			**-49.285**
Annuity per household (TH + SH = 6 Hh)			**-1.643**

Figure 147 *Investment costs Attenkirchen [21]*

Even though the storage and the solar panel system was constructed in a very cost efficient way, the total investment cost are quite high the heat generation costs are about 135 €/MWh according to the amortisation calculation illustrated in Figure 1476.

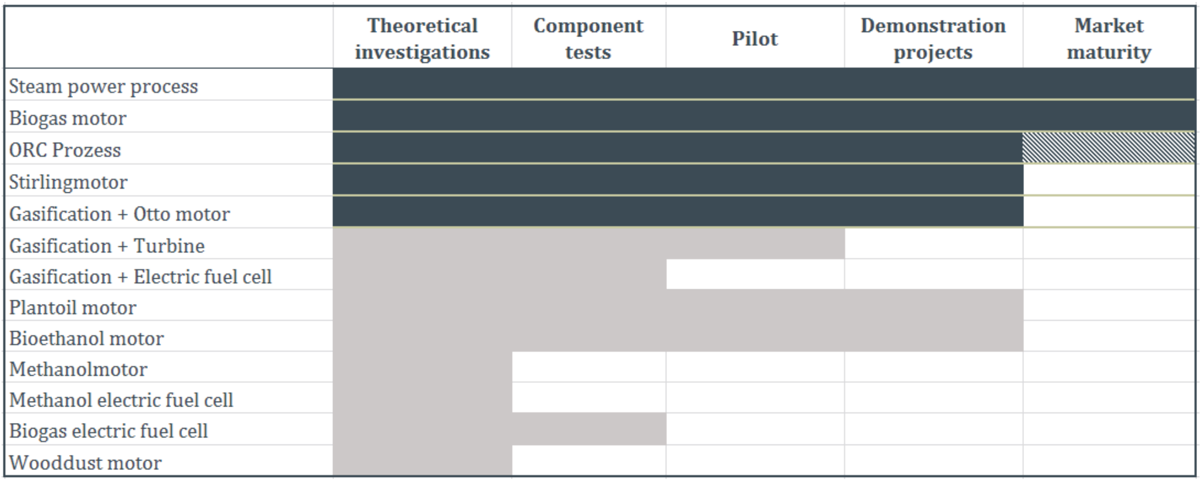
16.4.3 Conclusion – Solar storage systems

These systems cannot compete with classic gas heating systems, even if taking into account, that they were demonstration projects with some potential in reducing costs. This type of projects will be dependent on massive public support in future.

Nevertheless they can compete with other alternative energy sources such as shallow geothermal wells or single family solar systems. It might easily be that this system will be applied more often in future, as solar energy is very popular. However concerning pure economics it cannot prevail.

16.5 Thermal storage systems in combination with heat and power producing units (CHP)

Combined Heat and Power units are basically electricity generators which waste heat is used as heating energy. There are various different technical variations. The following table (Figure: 148), gives an overview of some.



	Theoretical investigations	Component tests	Pilot	Demonstration projects	Market maturity
Steam power process	■	■	■	■	■
Biogas motor	■	■	■	■	■
ORC Prozess	■	■	■	■	▨
Stirlingmotor	■	■	■	■	
Gasification + Otto motor	■	■	■	■	
Gasification + Turbine	▒	▒	▒		
Gasification + Electric fuel cell	▒	▒			
Plantoil motor	▒	▒	▒	▒	
Bioethanol motor	▒	▒	▒	▒	
Methanolmotor	▒				
Methanol electric fuel cell	▒				
Biogas electric fuel cell	▒	▒			
Wooddust motor	▒				

Figure 148 *CHP Unit technical variations*

As illustrated only the Steam power processes (Steam turbine and steam motor) and the biogas motor has achieved market maturity. Very popular in recent years in Austria and Germany was the construction of Biogas power plants utilizing a Gas motor. There are several 100 of facilities running in Middle Europe.

A storage system could be used to support the waste energy utilization of all CHP units, but due to actual state of the art this work focuses on Biogas power plants.

16.6 Thermal storage systems combined with biogas CHPs

16.6.1 Biogas CHPs

Please note that the following project description is done in the rough estimation mode; it is not a case study. It is a try to visualise the characteristics of such a project. It was not target to try to demonstrate exact values, which also would not make sense in a made up example In this mode basically the achievable revenues (including most important operation costs) there origination and major influences on them are illustrated, investment costs which are strongly dependent on local circumstances are given as possible ranges.

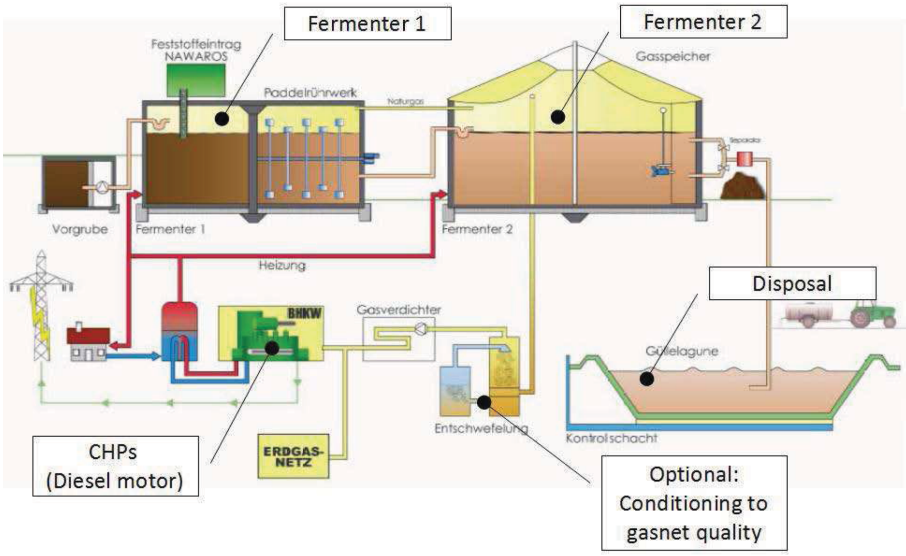


***Figure 149**: Major components of a biogas CHP station [modified 2]*

Not illustrated: Organic matter storage

Fermenter 1 and 2

The base material is normally semi liquid manure, organic matter from energy plants or from industry (e.g. clearing sludge, slaughter house, dairy disposal, etc.). The organic matter is brought into fermenter one to be split anaerobe (fermented) by bacteria, producing methane (and other) gas. To increase the speed of this process fermenter 1 is heated and stirred. The production of methane gas follows approximately a logarithmic function.

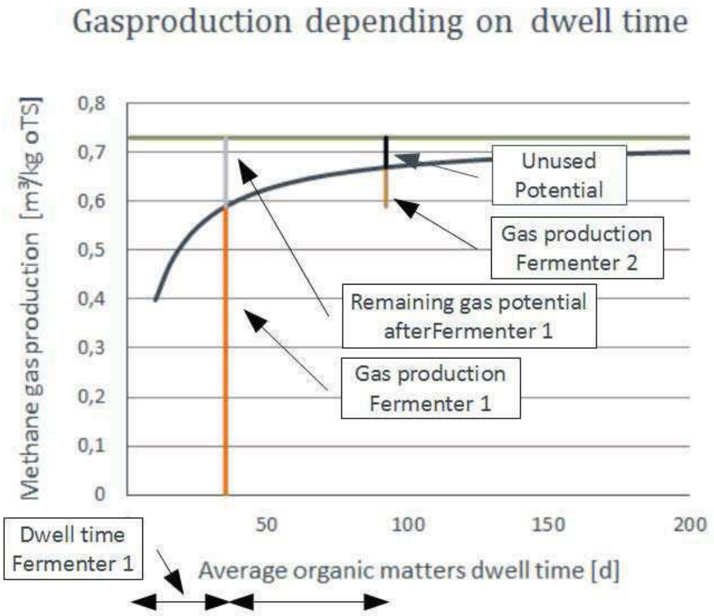


***Figure 150:** Gas production depending on dwell time [own illustration]*

Actual settings: organic matter: 66 ‘% semi liquid manure 33 % fleshy taproot

m³/kg oTS = m³ biogas per kg dry organic matter

At the beginning of the process methane gas is produced rapidly, after the easy split able organic matter is processed, the curve flattens out. The productivity increase due to stirring and heating does not pay back anymore. This is approximately (!) reached at the functions inflexion point. The organic matter is transferred to the 2nd Fermenter where some of the remaining gas potential is produced.

Note that the design of the fermenter sizes is an optimisation process.

$$V_{Fermenter} = OM_{Input} * t_{average}$$

Equation 33*: Fermenter volume*

$V_{Fermenter}$ = Fermenter Volume [m³]; OM_{Input}= Daily organic matter input [m³/d]; $t_{average}$ = Average dwell time [d]

$$Gasproduction = f(OM_{type}; t_{average\ 1\ u\ 2}; Fermenter\ type)$$

Equation 34: *Gas production*

Optimum Gas production is dependent of Organic matter type, average achievable dwell times in both fermenters (dependence of fermenter volumes) and the fermenter type

Please note that correct fermenter design is not an easy task and would require at least laboratory investigation of organic matter. In several reports it was established that the wrong design of the fermenter blocks is a major problem occurring regularly.

Disposal

The after the second fermentation step remaining organic matter is brought to a disposal zone, and used as fertilizer. Nowadays it is a federal requirement to dispose the remaining organic matter in a covered gas tight disposal zone to avoid methane gas escaping to the atmosphere. Therefore a bit more of the gas potential is recovered but without economic sense.

Conditioning of gas

There are in principle three target gas qualities:

1.) Gas quality allowing usage in a bio gas CHP unit
2.) Gas quality allowing gas being fed to a gas network (as substitution gas)
3.) Gas quality allowing gas being fed to a gas network (as additional gas)

Minimum required cleaning process steps for usage in a biogas CHP unit:

1.) Gas dehydration
2.) Raw desulphurisation

Minimum required cleaning process steps for usage as substation gas

1.) Gas dehydration
2.) Oxygen separation
3.) Fine desulphurisation
4.) CO_2 separation

Usage as additional gas means that biogas can be brought in a gas network if it is limited to an amount, in that the overall gas quality stays within the given quality range.

Gas dehydration

Gas dehydration is a governmental and technical requirement, as biogas condensate might cause corrosion in all concerned technical components. (Solute O_2, SO_2 and CO_2) Further water would disturb other cleaning processes and reduced CHP efficiency.

To accomplish there are two possible processes, for small amounts and usage in a biogas CHP most often condenser processes are used. Meaning the gas is compressed, cooled down on surrounding temperature and expanded via a valve. Due to the Joule Thomson effect it cools down beneath the dew point. The condensed water is than separated.

For larger amounts and higher quality processes including an adsorbent are used, including molecular sieves, silica gel, aluminium oxide and others.

Raw desulphurisation

The raw desulphurisation is done Fermenter intern, by adding iron chloride, which chemically bonds part of the sulphur. The resulting product can be separated from the organic matter as it settles down, due to higher weight. Additionally all products and by products are ecologically harmless.

Note that the raw desulphurisation is done regardless if a fine desulphurisation is adapted or not

Fine desulphurisation

There are various processes, for achieving natural gas quality a chemical washing is applied, using alkaline water as adsorbent.

Oxygen separation

Oxygen separation is done either in a Palladium-Platinum – catalyst or by chemical adsorption using Copper.

CO_2 separation

There are various techniques on the market. Most often referenced is the pressure swing adsorption (PSA). But also various different chemical washes are available.

CHP unit

In principle a combined heat and power unit can be constructed of a lot of motor or turbine types. Most important is the quality of the combustible. If it is liquid or gaseous it can be utilized in an Otto or Diesel motor process (biogas or bio oil), requiring low investment and operation cost at very good electrical and thermal efficiencies.

For low quality combustible like for example wood, the heat has to be transferred to a heating media (e.g. water) and brought to an e.g. Clausius Rankine process. As described these power plants require not compare able higher investment costs.

To make more biomass accessible to motor processes various techniques have been applied. For example wood is pulverised to yield an explosive mixture with air, which can be burned with in a motor. However, this process just works in laboratory. Already applied technology includes wood gas power plants or heat to mechanical work motors, as the legendary Stirling motor.

Without further explanation it was decided, that the biogas CHP's are most interesting. As they offer high efficiencies at relatively low costs, and reliable data is available. Additionally the federal support is generous.

The following electric efficiency and cost function is for CHPs utilizing natural gas. Biogas and bio oil CHPS offer slightly lower efficiencies and slightly higher costs.

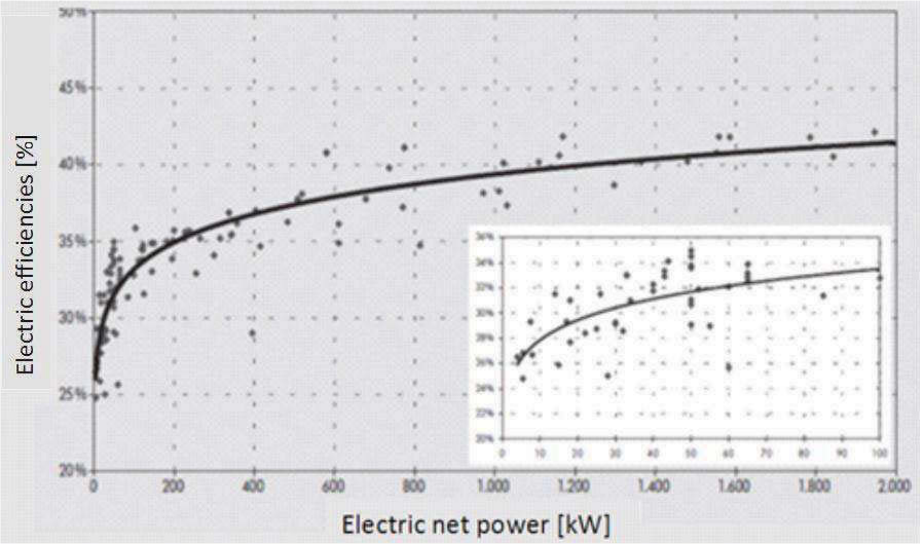


Figure 151: *Electric efficiency vs. electric net power [15]*

16.6.1.1 Achievable revenues and federal support

Germany:

Basis support:

0 – 150 kW	116, 7	€/MWh
0 – 500 kW	91, 8	€/MWh
500 – 5000 kW	82, 5	€/MWh
5000 – 20000 kW	77, 9	€/MW

Bonus

Technology bonus:	+ 20	€/MWh
Utilization of heating energy	+ 30	€/MWh
Avoiding of Formaldehyde	+ 10	€/MWh
Using landscape work organic waste		
0 – 500 kW	+ 20	€/MWh
Using only renewable energy source		
0 - 500 kW	+ 70	€/MWh
500 – 5000 kW	+40	€/MWh
Using manure		
0 – 150 kW	+ 40	€/MWh
150 – 500 kW	+ 10	€/MWh
Using wood gas		
0 – 5000 kW	+ 25	€/MWh

The exact requirements for qualifying to a certain bonus or basis support are not listed here. Instead the original law is referenced “Erneuerbare Energien Gesetz Novellierung 2009”

(The programme will calculate the bonus automatically)

Austria:

In Austria the federal support system is less complex. There is a basis support depending on the size

Basis support

0 – 100 kW	169, 3 €/MWh
100 – 250 kW	151, 3 €/MWh
250 – 500 kW	139, 8 €/MWh
500 – 1000 kW	123, 8 €/MWh
1000 - kW	112, 8 €/MWh
Co fermentation of organic industrial waste:	- 30 %

Fermentation of clearing sludge	59, 3	€/MWh
Fermentation of disposal gases	40, 3	€/MWh

Bonus

Price protection on organic matter	+ up to 40 €/MWh (in years of high fuel prices)
Technology bonus	+ 20 €/MWh
High efficient facilities (KWK bonus)	+20 €/MWh

The exact requirements for qualifying to a certain bonus or basis support are not listed here. Instead the original law is referenced “Ökostrom gesetz Novelle 2009”.

Calculation mode difference Austria - Germany

Basis support

If a plant in Germany produces for example 200 kW, and does not qualify for any additional bonus, 150 kW would achieve a support of 116, 7 [€/MWh] the remaining 50 kW 91, 8 [€/MWh].

The same plant in Austria would achieve a support of 151, 3 [€/MWh], for the total production.

(Please do not get mislead by the example, federal support is higher in Germany for most real cases)

KWK Bonus

If a plant in Germany utilizes 20 % of its waste heat also 20 % of the KWK Bonus can be claimed.

In Austria the same plant would not qualify for any bonus, but it could claim the total bonus if it achieves a waste energy utilisation of approximately 90 % (or more exact if the equation (2/3) Heating Energy / Fuel Energy + Electric Energy / Fuel Energy > 0, 6)

This speciality of the Austrian legislation could open an economic gap for storage systems, if a facility could achieve the total bonus with the help of a geothermal storage.

Achievable revenues

Regardless the exact amount of the federal support it is important to recognise, that it is just given if a certain (very high) amount of the rest heating energy is used. This is in most cases only possible during the cold months of the year.

To avoid this in some cases heating energy costumers are created which demand energy over the year. Such as fish ponds or green houses, another possibility would be the implementing of a seasonal storage system.

Revenues from electric energy production alone are consider able

Example:

Assumed is a small CHPs (250 kW electric net power) situated in Austria, receiving only basic federal support. The project value is calculated with an internal rate of return I = 7 % and a project life time of 15 years. Values calculated from electricity power sale alone

Yearly revenues

(8600 h online):	**325.000 €**
(5500 h online)	**207.000 €**

Project value after 15 years:

(8600 h online)	**2.900.000 €**
(5500 h online)	**1.850.000 €**

The example shall point out how important online hours per year are for the projects economics. This simple calculation is the basic for the idea to combine biogas CHPs with a seasonal underground storage system. More detailed data will be provided in the project type description.

16.6.1.2 Cost functions

Fermentation unit

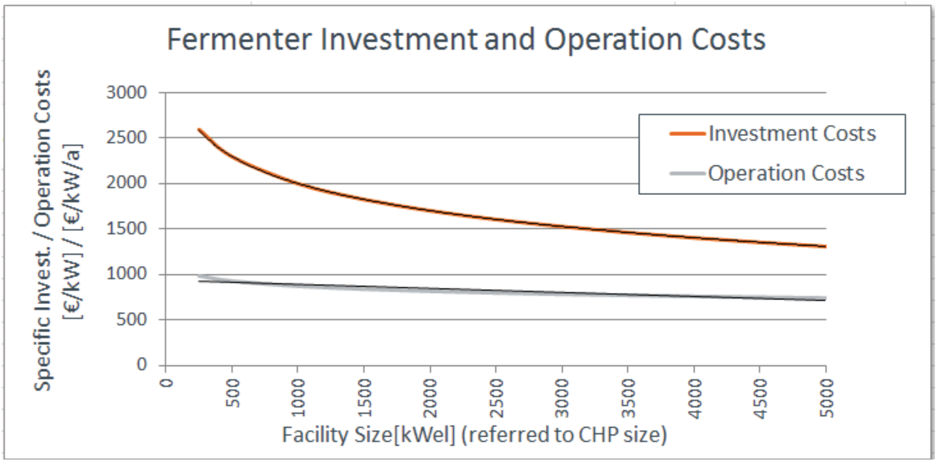


Figure 152 *Investment costs vs. electric net power (referred to maximal fitting biogas CHPU size η=40%*

CHP unit

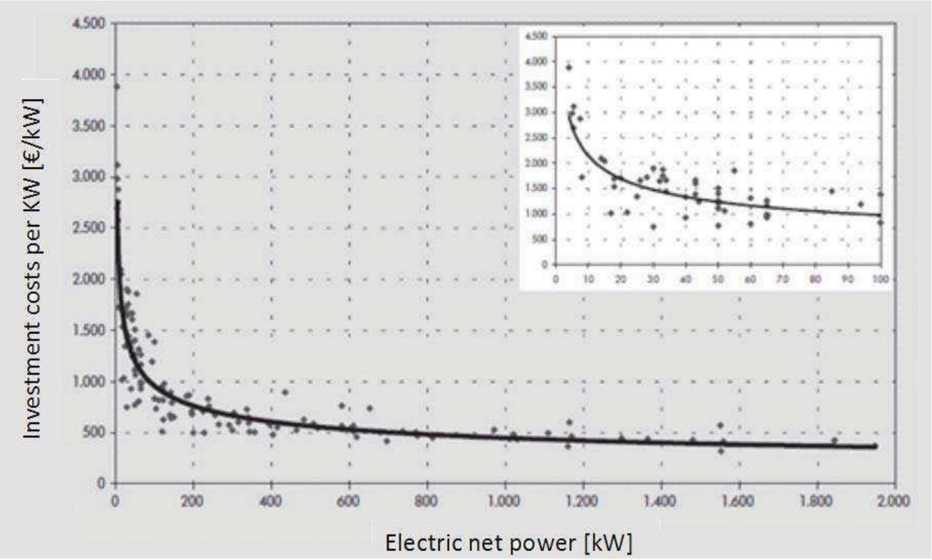


Figure 153: *Investment costs vs. electric net power [15]*

Gas preparation - Investment and operation costs

The calculation of the investment and operating costs for the gas preparation will not be listed here. For further information original literature is referenced: "Beseitigung technischer, rechtlicher und ökonomischer Hemmnisse bei der Einspeisung biogener Gase in das Erdgasnetz zur Reduzierung klimarelevanter Emissionen durch Aufbau und Anwendung einer georeferenzierten Datenbank" [Fraunhofer Institut / Umsicht]

All cost functions applied by the evaluation software originate from this publication. Functions were created according to the described examples.

16.7 Evaluation software – Biogas CHP units

Task of this software is to evaluate net electricity and heat power for the planned CHP units. Additional it shall provide cost functions for all major components: CHP; Fermentation unit; storage; gas cleaning;

As for all energy supplying components, the demand line and the according energy concept needs to be input before.

16.7.1 Pre design of CHP unit

aktiver Slot	1	
Lastträger nummer	1	[]
Errichtungsjahr	1	[]
Leistung -thermisch	800	[kW]
BHKW Typ	Biogas	[]

*Natural gas plants can be chosen if gas cleaning is performed

Thermal efficiency		
Minimum	50	[%]
Chosen	54	[%]
Maximum	67	[%]
Electric efficiency		
Minimum	37	[%]
Chosen	39	[%]
Maximum	46	[%]
Total efficiency		
Minimum	70	[%]
Chosen	93	[%]
Maximum	98	[%]

Figure 154 *Basic CHP unit settings [own illustration]*

RN1

Determines which supplier is active, all settings will be imbued on it. In case that more than one CHP unit needs to be designed

RN 2

Basic settings planned in the energy concept. Most important is the required net heat output, as the CHP is designed according to it.

RN 3

There are various types of biomass CHP units, this programme provides cost and efficiency functions for bio oil, biogas and natural gas units. (All utilising Diesel motors)

RN 4

Maximum, minimum and a most probable value is plotted, for thermal and electrical efficiency, after the program has recognized the size of the CHP unit, according to the settings in RN 1. As this settings are fundamental important, they can be changed within the given ranges by hand.

16.7.2 Federal support

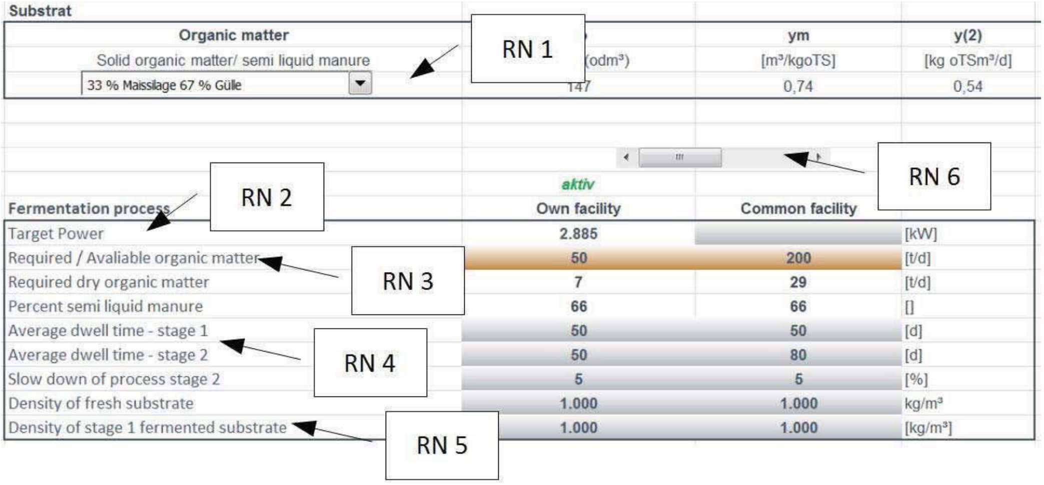
The program calculates the basic support and some remarkable numbers which helps to decide if the plant applies for a certain additional bonus or not. If it is decided that the plant most likely will receive a certain support it can be simply ticked on in a list.

16.7.3 Pre design of fermenter unit

For this part of the facility main interest is on the investment and operation costs. If this is the case the programme usually just uses a predefined cost function to suggest a value. Unfortunately the published cost functions for Fermenter units yield wide spread results.

The programme will display suggestions from [Waller; Laber and Urban]. These cost functions have in common, that they refer to the net gas output or even the net electricity output of the total unit. Regardless the type of organic matter or other differing circumstances. The cost functions constructed from [Urbans] investigations provide values for facilities depending on usage of mainly silage semi liquid manure.

In the authors opinion the fermenter costs should be calculated according to the size of the required main components. This includes at least a pre design of fermenter units, the storage and the gas cleaning facility.



Substrat

Organic matter		ym	y(2)
Solid organic matter/ semi liquid manure	(odm³)	[m³/kgoTS]	[kg oTSm³/d]
33 % Maissilage 67 % Gülle	147	0,74	0,54

aktiv

Fermentation process	Own facility	Common facility	
Target Power	2.885		[kW]
Required / Avaliable organic matter	50	200	[t/d]
Required dry organic matter	7	29	[t/d]
Percent semi liquid manure	66	66	[]
Average dwell time - stage 1	50	50	[d]
Average dwell time - stage 2	50	80	[d]
Slow down of process stage 2	5	5	[%]
Density of fresh substrate	1.000	1.000	kg/m³
Density of stage 1 fermented substrate	1.000	1.000	[kg/m³]

Figure 155 Predesign of fermenter unit 1 [own illustration]

RN 1

Various different organic matters and its fermentation behaviour can be displayed. The chosen type influences the shape of the fermentation behaviour curve.

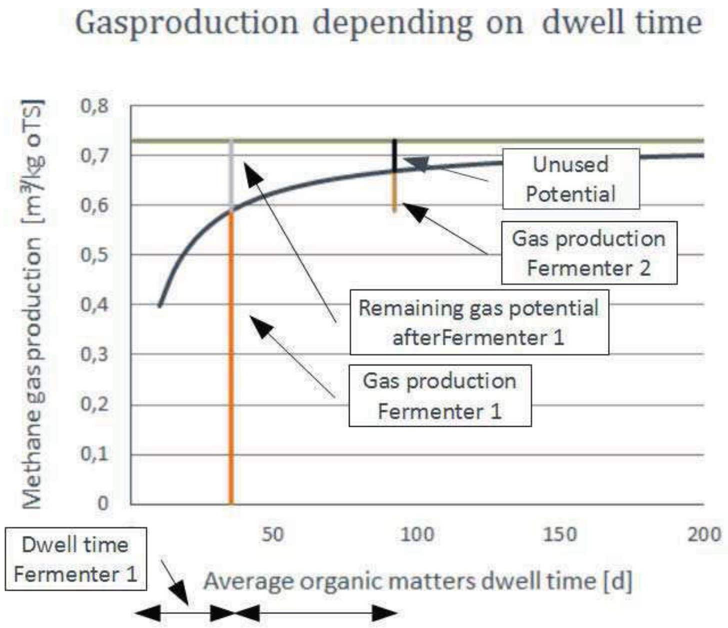


Figure 156 *Displayed fermentation behaviour curve*

RN 2

Displays the total required amount of biogas for all CHP units considered in the energy concept pre design

RN 3

A target value search can be performed to find the required daily amount of organic matter to satisfy the requirements, according to the fermentation process settings.

RN 4

The average dwell time for both stages can be input and is displayed in Figure 156 *Displayed fermentation behaviour curve*. This setting will influence the total gas output as well as the fermenter volumes.

The cell " Slowdown of process stage 2" input reference to the different dwell time value of the fermenter stages, as the first one is stirred and heated. The curve was constructed in laboratory test using just one heated and stirred fermenter. Therefore the setting will reduce the value of the dwell time in the second fermenter. E.g.: If the value is set to 10 % and the average dwell time in the second stage to 50 days, the gas production value of 45 days is calculated.

RN 5

Densities of fresh and partly fermented organic matter need to be known, to calculate according necessary volumes.

RN 6

It is also possible to take into account, that one fermenter is used for multiple energy supply projects, being connected via a gas net. The relative investment costs are likely to shrink, and will be split by the program according to the gas demand.

16.7.4 Investment cost calculation

Fermentation unit

After these settings are input the required volumes of the fermenter units and the organic matter storage can be calculated. A cost suggestion is done by functions referring to the volumes of these main facility parts.

1.) Fermenter 1
2.) Steering machine
3.) Fermenter 2
4.) Organic matter storage
5.) Final disposal
6.) Others

The required data was taken from the investigations of [Urban 2006]

Gas cleaning

Gas cleaning cost functions are completely copied from reference [36]

CHP unit

CHP unit cost functions were taken from “[ASUE – Kenndaten Blockheizkraftwerke – 2005]

16.8 Projects description: Heat energy storage combined with Biogas CHP

16.8.1 Comment

Please note that the following project description is done in rough estimation mode; it is not a case study. It is a try to visualise the characteristics of such a project. It was not target to try to demonstrate exact values, which also would not make sense in a made up example In this mode basically the achievable revenues (including most important operation costs) there origination and major influences on them are illustrated, investment costs which are strongly dependent on local circumstances are given as possible ranges.

16.8.2 Assumptions

As there are various different possibilities of using the waste energy from CHP units, each project should be threated individually.

In this case it is assumed that:

1. A new biogas facility is constructed.
2. The biogas facility supplies a district heating system.
3. The biogas facility is operated in strict heating demand operation mode

Comment to assumption 3

It shall be point out at the beginning of these chapter that assumption three is not valid in reality (yet). Biogas facilities are usually not heating demand but power demand operated, which basically means turned on 8600 hours per year, if possible – regardless of the amount of waste energy that can be utilized.

Nevertheless an investigation of these theoretical circumstances is interesting, as the basic idea is to allow the storage system to profit from potential bonuses on high amounts of heat energy utilized or by qualifying a facility for federal support by assisting achieving a minimum efficiency benchmark. As these juridical circumstances change frequently over time, between the countries, and additionally there are multiple variations of heat energy usage, this simplified assumption is done to investigate the potential.

16.8.3 Project set up

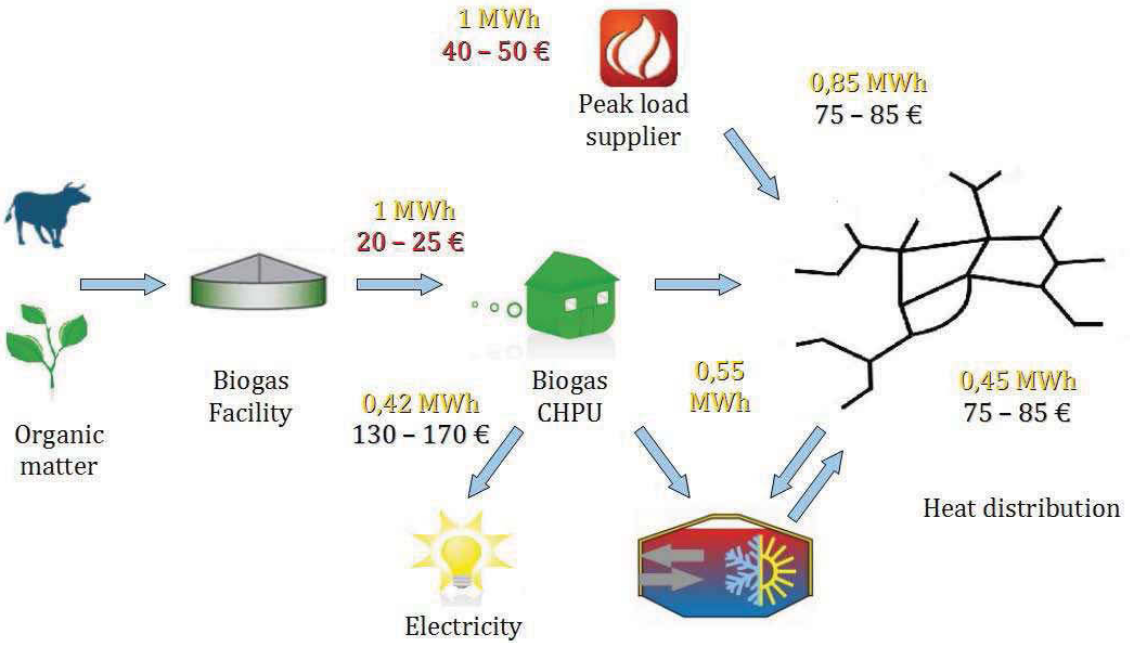


Figure 157: *Project set up of a biogas CHP including a geothermal storage [own illustration]*

Illustrated are origination and costs (red) / price (black) of energies. The energy originates from organic matter, causing costs of 20 – 25 €/MWh. The energy is transferred to the CHP where it is turned to electricity and heating energy. (Typically with electric efficiency ratings about 40 %, and thermal efficiency of about 55 %) Electricity is sold at the supported price of 130 – 170 €/MWh. Heating energy is sold on the free market achieving prices of 75 – 85 €/MWh.

16.8.4 Theoretical creation of value

	Type	Energy [MWh]	Cost / Price [€/MWh]	Result [€/MWh]
Created energy	Heat	1	22	-22
Produced electricity	Electric	0,40	150	60
Produced heating energy	Heat	0,52	-	-
Sold heating energy (-network losses)	Electric	0,40	75	30
Total				68

Figure 158: *Theoretical creation of value - Biomass CHP [own illustration]*

Exact values are dependent on location and size of CHP

Advantages

- (At least) two third of the revenues originate from electricity sale
  -> Resulting in very fast development and predictable revenues
  -> Even if produced heat energy is lost in network or storage system, the electric by production will still create a positive balance.
- The theoretical creation of electricity is in the same magnitude as large geothermal wells utilizing ORC processes.
- The small size of the project (Net heating power around 0,3 to 2 MW) allows small networks, which also increases revenue development from heating energy sale
- Small network can apply techniques to safe costs
- Customer behaviour is relatively easy predictable
- Low absolute investment costs required - capped investment supports will cover a higher percentage than in large scale projects.

Drawbacks

- Organic matter demand may be concurring with food production
- Noise and odour emissions

Effects of storage system on total economics

16.8.5 Increase of economics due to straightening of static demand line

Example

A small village of 300 Single family homes shall be supported with a biogas CHP unit and an unlimited storage system.

CHP unit:

Electric efficiency: 40 %

Thermal efficiency: 50 %.

Energy Costs / Prices:

Electricity price: 123, 8 €/MWh

Heating energy price: 70 €/MWh

Organic matter price: 30 €/MWh

Revenues from peak load: 30 €/MWh

Storage

Case 1: no storage included

Case 2: 90 % efficiency storage included

Case 3 75 % efficiency storage included

Demand line for the investigated cases

Network

Due to the rather small network a fast customer adaption is assumed:

Customer behaviour: (50/100/3log) [Start value/End value/Delay/Function]

Operation costs

Heating fermenter unit 15 % of heating energy revenues

Other operating cost are included in organic matter costs (+ 5 €/MWh)

Demand lines and possible heat energy supply

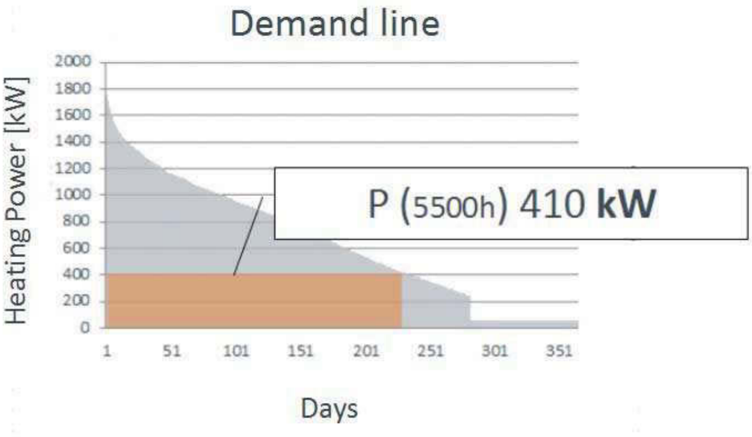


Figure 159: *Case 1 - No storage included – Demand line and heat energy support [own illustration]*

Assumed is a strict heating demand energy operated CHP unit, which is 5500 hours per year online, resulting in a net heating power of 410 kW

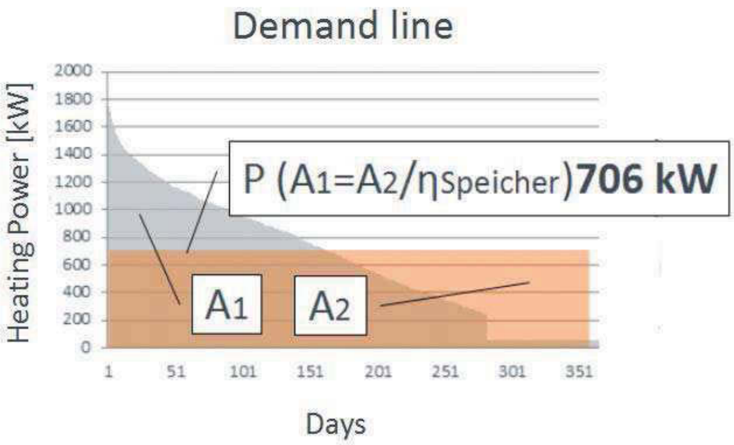


Figure 160: *Case 2 - ή= 90 % storage included – Demand line and heat energy support [own illustration]*

A unit of 706 kW net heating power running 8600 h per year, can be installed serving the same demand line.

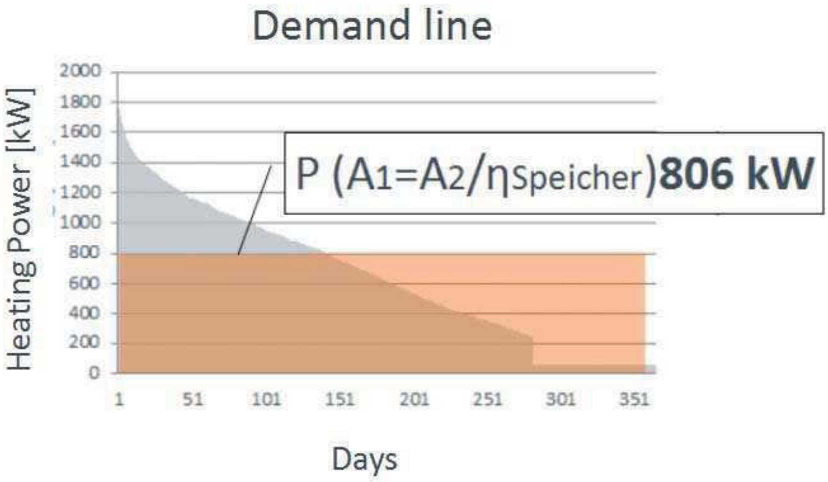


Figure 161: *Case 3 - ή= 75% storage included – Demand line and heat energy support [own illustration]*

Reduction of storage efficiency naturally further increases the required CHP units' net heating power

Comparison of the investigated projects

Compared are the net power ratings, the theoretical revenues per year (assuming 100 % of costumers connected) and the theoretical project value after a project life of 15 years applying an internal rate of return of 7%.

	Hours online	Net themal power	Electric power	Required Biogas power
	[h]	[kW]	[kW]	[kW]
Case 1	5.500	410	328	820
Case 2	8.600	706	565	1.412
Case 3	8.600	806	645	1.612

Figure 162: *Comparison of power ratings and online time [own illustration]*

	Revenues from heat energy*	Revenues from electricity	Revenues from peakload	Organic matter costs	Theoretical revenues	Theoretical Project value
	[€/y]	[€/y]	[€/y]	[€/y]	[€/y]	[€]
Case 1	190.000	223.000	133.000	-135.000	411.000	3.365.000
Case 2	381.000	601.000	0	-364.000	618.000	5.060.000
Case 3	381.000	687.000	0	-416.000	651.000	5.338.000

Figure 163*: Comparison of project economics [own illustration]*

Simplified calculation neglecting network losses

Result

The project value increases about 140 to 175 % if a storage system is included, for this rather small energy supply example, an installation of a storage system would payback if it has **investment costs of lower than 2.000.000 €** (assuming zero operation costs). The required storage system would need an average capacity of 1300 MWh, resulting in a required sediment volume of approximately 30.000 m³, or a cylindrical shaped body of 30 m height and a radius of 18 m (typical water rock properties and a usable temperature difference of 50°C assumed).

Please note that the size of the storage system is depending strongly on the temperature difference of stored temperature and network backflow temperature

Also remark able is that the storage system offering the lower efficiency results in a higher project value. This is because the additional organic matter costs are more than balanced by the additional revenues from electricity sale.

Influence on storage efficiency on economics

A sensitivity analysis was performed investigating the influx of storage efficiency on the projects revenues, relative to the revenues with a storage efficiency of 100 %. All settings are according to the given example.

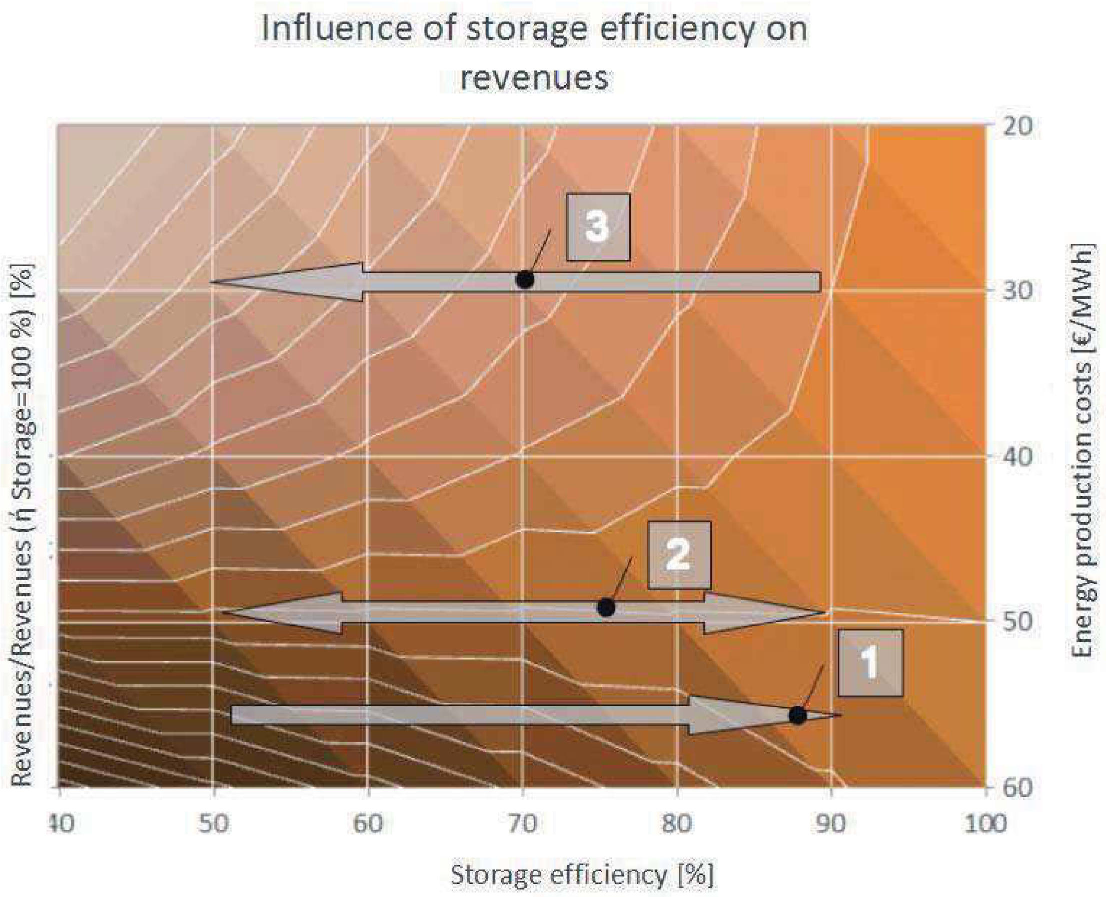


Figure 164: *Influence of storage efficiency on revenues [own illustration]*

Dark = relative lower revenues; Settings according to the previous example

Basically three areas can be identified:

1.) Energy production costs **> 50 €/MWh**
 -> Revenues increase with better storage efficiency
2.) Energy production costs **~ 50 €/MWh**
 -> Revenues are independent of storage efficiency
3.) Energy production costs **< 50 €/MWh**
 -> Revenues increase with lower storage efficiency

Note that the minimum storage efficiency is limited due to minimum allowed system efficiency to qualify for federal support. However, it can be stated that biogas energy production costs are typically between 25 and 40 €/MWh (including price for organic matter and operation costs). Therefore high storage efficiencies are not an issue in this type of projects, at least as long as federal support is given on electricity price. The by far more important storage property is size, input/output capacity and of course investment costs.

16.8.6 Increase of economic due to straightening of dynamic demand line

As previously discussed in most projects, even if they are of small size it will take a few years until all costumers have connected to the network. This results in a lower demand in the early project years which delays revenues and significantly reduces the project value, especially if high internal rates of return are anticipated.

Storage systems characteristcly need buffer heat, or in other words, they have an lower efficiency and therefore an higher demand in the first project years. Therefore they are able to straighten the dynamic demand line. Due to the discussed fact that positiv revenue is created, even if heat energy is lost this has a positive effect on the total project value.

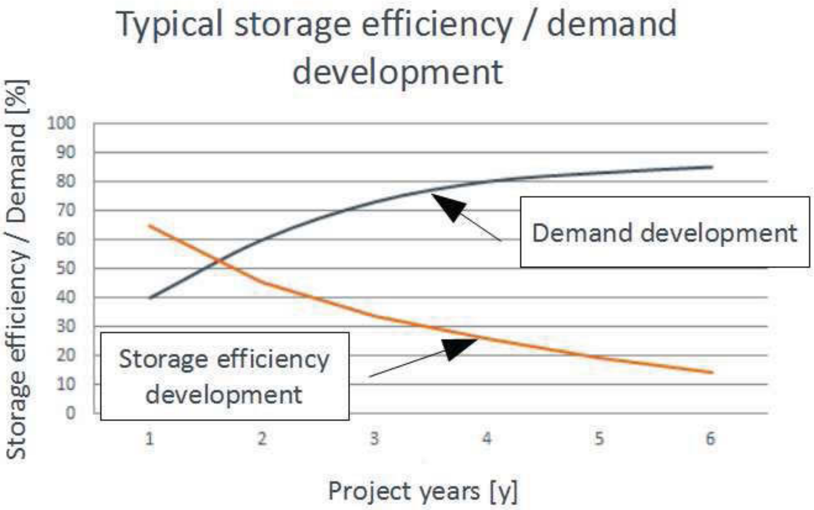


Figure 165: *Typical storage efficiency and demand development [own illustration]*

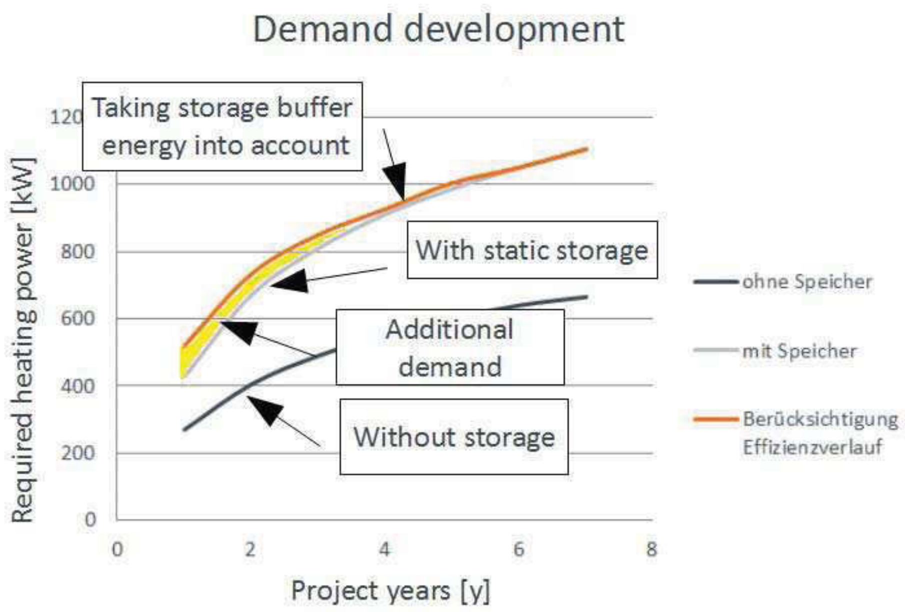


Figure 166:Straightening of the dynamic demand line [own illustration]

Strongly dependent on the individual circumstances concerning organic matter costs, network built up speed; project life time and achievable prices, the straightening of the demand development will result in approximately around 5 % increase of total project value.

Investment costs

The given investment costs are a rough estimate referring to case 2

1000 kW Fermentation unit:	750.000 – 1.500.000 €
560 kW Biogas CHP unit	250.000 – 300.000 €
300 single family home network	500.000 – 2.000.000 €
Others	500.000 €
1300 MWh storage system:	?
Total:	**2.000.000 – 4.300.000 € + Storage**
Total theoretical project value:	~ 5.000.000 €
Project value:	**700.000 – 3.000.000 € - Storage I / O costs**

16.8.7 Conclusion – large scale geothermal heating supply projects

General

The economics of this project type depends whether a fitting storage system can be developed. Especially interesting are (due to the stepwise federal support schema) storage sizes fitting to biogas plants of the size 100,250 and 500 kW thermal efficiency.

Resulting in approximate required storage sizes of: 300 MWh, 750 MWh and 1500 MWh and a customer demand equal to approximately 40, 100 and 200 single family homes. The required earth volume is governed by the achievable storage and network backflow temperature.

Potential

If fitting storage systems can be developed and constructed at acceptable investment and operation costs, the potential can be considered as very high. Actual there are more than 5000 bio gas plants of a fitting size on line in Germany and another 300 in Austria. Additional these storages might also improve the economics of other heat suppliers.

Challenges / Risks

Development of storage system, network costs, odour and noise nuisance of costumers

Perspectives

This type of project is like made for the petroleum industry, as they have knowledge, technology and equipment to handle: exploration, geology, drilling, reservoir engineering and production. Required to develop construct and run a heat storage system. In the author’s opinion there is reason for cautious optimism, for a profitable business in the renewable energy sector arising.

16.9 CHP biogas units combined with geothermal storage including gas preparation

This project type arises from the idea to utilize the gas net of RAG Company to further improve the overall economics of CHP units (combined with a geothermal storage). During developing multiple gas wells and being a major player in the gas storage business, Rag has implemented a fine mashed gas net all over Upper Austria.

16.9.1 Project set up

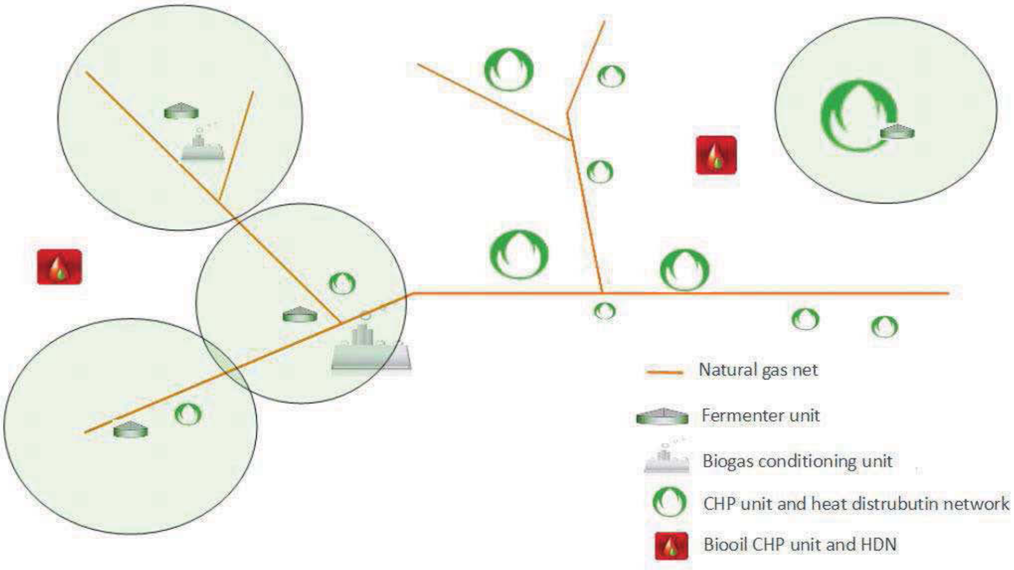


Figure 167: *Project set up -CHP units including geothermal storage and gas net*

16.9.2 Anticipated advantages

The basic idea is to split gas production from gas utilisation in a CHP unit. Following effects are anticipated:

1.) <u>Ideal location of fermenter unit</u>
-> Ideal size – reduction in relative investment costs
-> high biomass potential and little transport costs
-> odour and noise nuisance of costumers

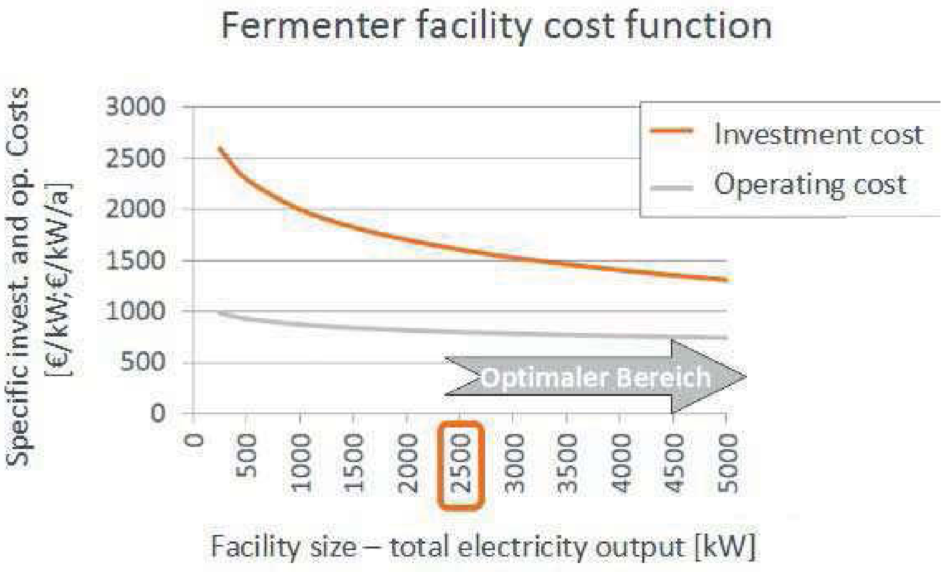


Figure 168: *Fermenter facility investment and operation cost function*

Values referring to resulting electric power output in a 40 % electrical efficiency CHP unit. The optimum range concerning costs is above 2500 MWh. Note that the optimum size is also dependent of the biomass transportation costs. If the increasing of fermenter unit requires a catchment area of larger than approximately 10 to 20 km in radius, it most likely will not pay back.

2.) <u>Ideal location of CHP unit</u>
-> Ideal size – reduction in relative investment and maximum support

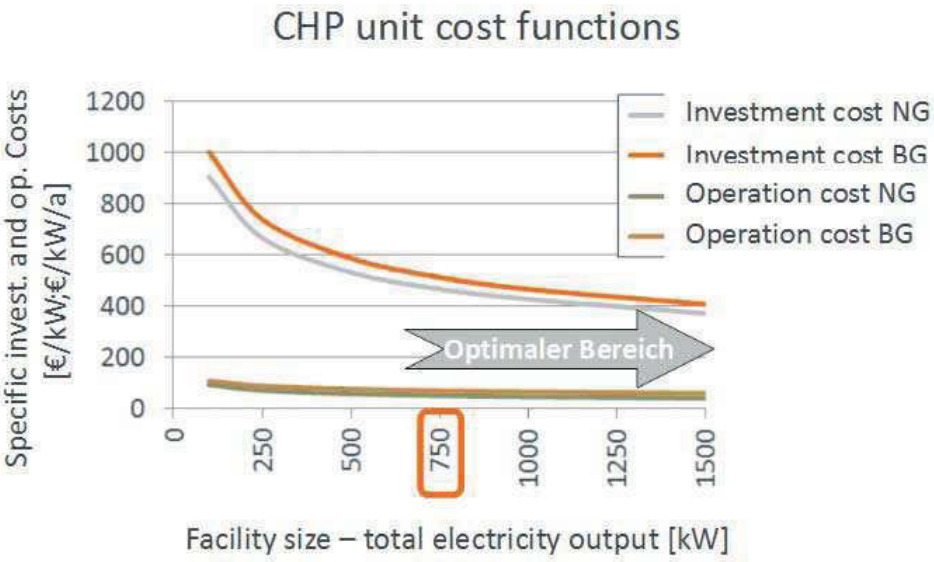


Figure 169:*CHP unit investment and operation costs NG = Natural gas; BG = Biogas*

The optimum range concerning cost functions start at approximately at a net power output of 500 to 750 kW. (So does the electrical efficiency function)

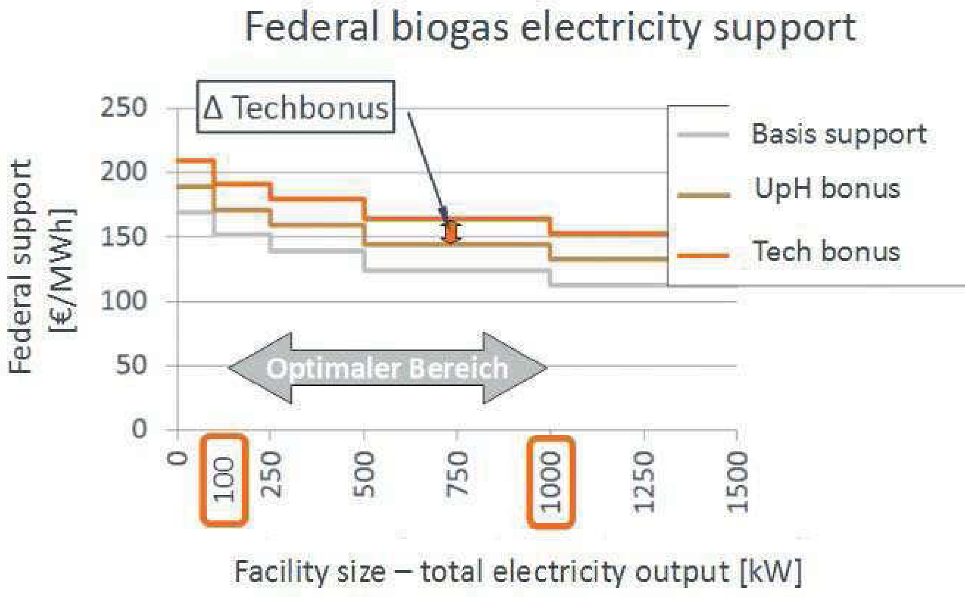


Figure 170:*federal biogas electricity support UoH: Utilizing of Heating Energy*

3.) <u>Qualifying for technology and formaldehyde bonus</u>

4.) <u>Flexibility in gas usage</u>

-> after federal support biogas CHP could be substituted by another heat source taking advantage of already developed network and heat storage. The biogas could be used e.g. as fuel or another different application.

16.9.3 Drawbacks

Major and single draw back are the investment and operation costs of gas conditioning. For further information and cost functions for different systems again original literature is referenced : "Beseitigung technischer, rechtlicher und ökonomischer Hemmnisse bei der Einspeisung biogener Gase in das Erdgasnetz zur Reduzierung klimarelevanter Emissionen durch Aufbau und Anwendung einer georeferenzierten Datenbank"

16.9.4 Conclusion – Biogas preparation

Basically the same statements as are valid, independently if a gas conditioning and a gas net are included or not. Basic question is, if the benefits originating from optimum location and size will surpass the originating costs from gas conditioning and transport (usage of existing gas net). First estimations applying the referenced cost functions, indicates that benefits and losses are approximately equal tending to a slight advantage for including a (already existing) gas network.

The advantages of greater flexibility and avoiding of odour and noise annoyance of customers however remains.

16.10 Comparison of biogas CHPU project assumptions to reality

Unfortunately, useful heat energy utilisation, even though desired by the legislator, has never prevailed in practise. It has been common practise to full fill the minimum requirements by generous heating or uneconomic applications. This one clear outcome of an investigation done by C.A.R.M.E.N

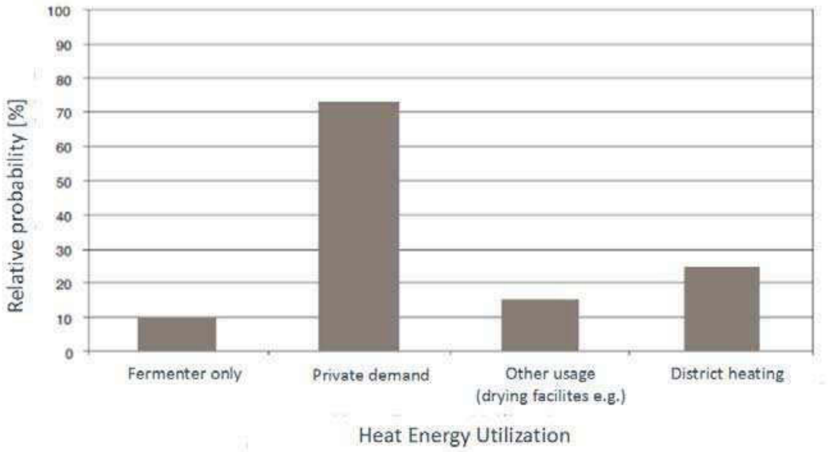


Figure 171 *Heat energy utilisation of 61 compared biogas facilities in Bavaria [23]*

As illustrated most facilities use their energy only for their fermentation units or for private demand, real economic utilisation is rather seldom. Even though there is a guideline to utilize at least 60 % of the total heat energy, this is rather seldom accomplished in practice on average approximately 25 % are utilized.

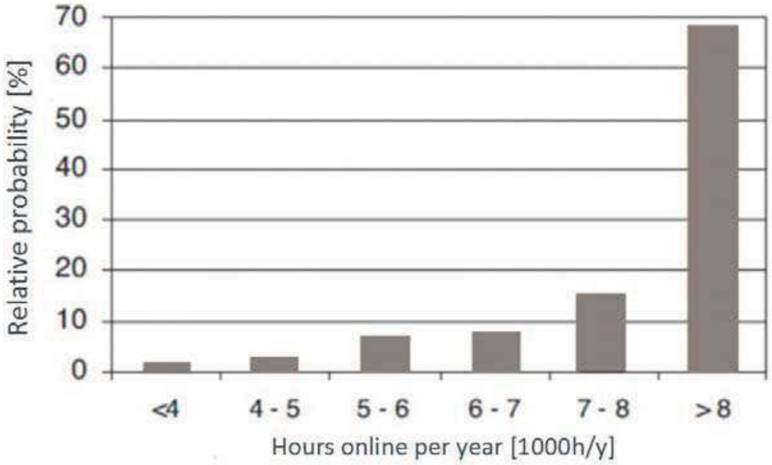


Figure 172 *Online hours per year of 61 compared biogas facilities in Bavaria [23]*

As can be seen in Figure 171, most biogas facilities run more than 8000 hours per year, the plants that cannot achieve this usually have problems with supporting the necessary biomass, not with their heat energy concept.

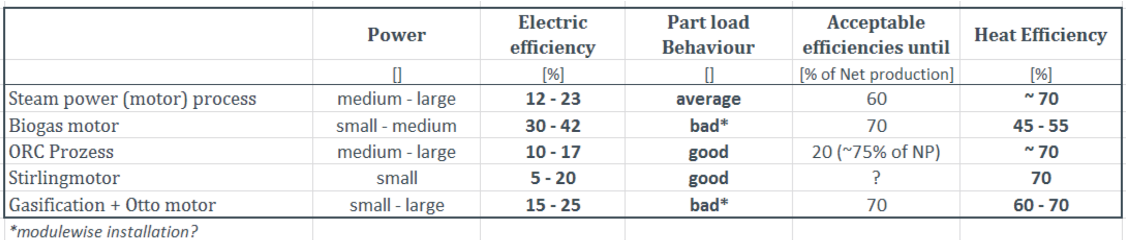
Basically the outcome is, that the assumption of a strictly heat operated CHP unit is - as known before - not valid. However as the requirements of the amount of heat that needs to be utilized is becoming more challenging, it might easily be that storage systems can assist in achieving the qualification for federal support or profit from extra bonus concerning high amount of heat utilized.

16.10.1 Conclusion biogas CHPs and geothermal storage

Under the given assumptions heat energy storage yields interesting economic results. In reality however most plants run, if their heat energy is used or not. Nevertheless a high efficient heating demand system can be decisive if federal support is given or not. In addition there are some loop holes, where seasonal storage system can profit from federal electricity support nevertheless.

For example the described KWK Bonus System in Austria there which is guaranteed for the total electricity produced if the total efficiency is above 90 %, a storage system could help to achieve this.

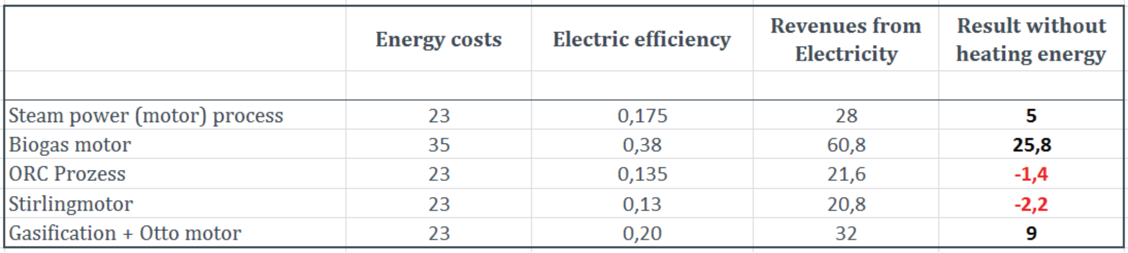
16.11 Heat energy Storage combined with other CHPs



	Power	**Electric efficiency**	**Part load Behaviour**	**Acceptable efficiencies until**	**Heat Efficiency**
	[]	[%]	[]	[% of Net production]	[%]
Steam power (motor) process	medium - large	**12 - 23**	**average**	60	**~ 70**
Biogas motor	small - medium	**30 - 42**	**bad***	70	**45 - 55**
ORC Prozess	medium - large	**10 - 17**	**good**	20 (~75% of NP)	**~ 70**
Stirlingmotor	small	**5 - 20**	**good**	?	**70**
Gasification + Otto motor	small - large	**15 - 25**	**bad***	70	**60 - 70**

**modulewise installation?*

Figure 173 *Technical Comparisons of CHP Units*



	Energy costs	**Electric efficiency**	**Revenues from Electricity**	**Result without heating energy**
Steam power (motor) process	23	0,175	28	**5**
Biogas motor	35	0,38	60,8	**25,8**
ORC Prozess	23	0,135	21,6	**-1,4**
Stirlingmotor	23	0,13	20,8	**-2,2**
Gasification + Otto motor	23	0,20	32	**9**

Figure 172 *Creation of value from Electric Energy of different CHP units*

Illustrated is the creation of value from different CHP units which have achieved market maturity or are close to that state. The electric energy price was assumed to be 160 €/MWh. Energy price for the biogas facility was assumed to be corn at a price of 35 €/MWh. For all other CHPUs the energy source was assumed to be wood at a price of 23 €/MWh

As can be seen clearly, the biogas facility can achieve considerable revenues even if no heat is economically used. However, due to the lower electric efficiencies this is not true for all other CHP units. Especially if it is considered that there was no operation costs taken into account.

CHP units applying one of these other technologies than biogas motors are in need of heat energy usage, and in fact these CHP types are operated strictly on heating demand! This means that, the assumptions done for the Biogas facilities are valid here.

However beside the steam motor none of these technologies has achieved market maturity, there are still unsolved problems especially concerning long term duration.

16.11.1 Potential

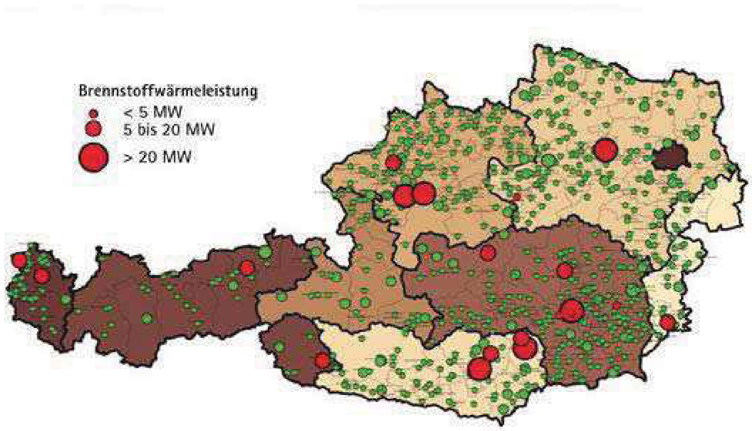


Figure 174 *Illustration of Austrian biomass (wood) heating power plants (green) and biomass CHP Units (red) 2007 [19]*

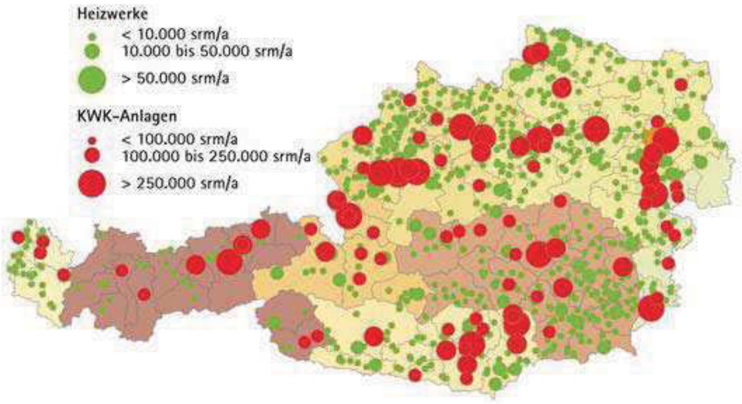


Figure 175 *Illustration of Austrian biomass (wood) heating power plants (green) and biomass CHP Units (red) 2010 [19]*

As illustrated the application of CHP Units is increasing, the utilized technology is mainly ORC, but also others - One well known project is the wood gasification power plant in Füssing, which achieves online hours of more than 7500 per year. Theoretically there are numerous locations that could profit from al large scale thermal storage if they have a seasonal dependent heat demand and decide to use CHP technology.

16.12 Project description: Heat energy storage combined with other CHP

(Investigations for this chapter was done during working for ADS, but with regard to contents it was added to the first section)

16.12.1 Comment

Please note that the following project description is done in the rough estimation mode; it is not a case study. It is a try to visualise the characteristics of such a project. It was not target to try to demonstrate exact values, which also would not make sense in a made up example In this mode basically the achievable revenues (including most important operation costs) there origination and major influences on them are illustrated, investment costs which are strongly dependent on local circumstances are given as possible ranges.

16.12.2 Project set up

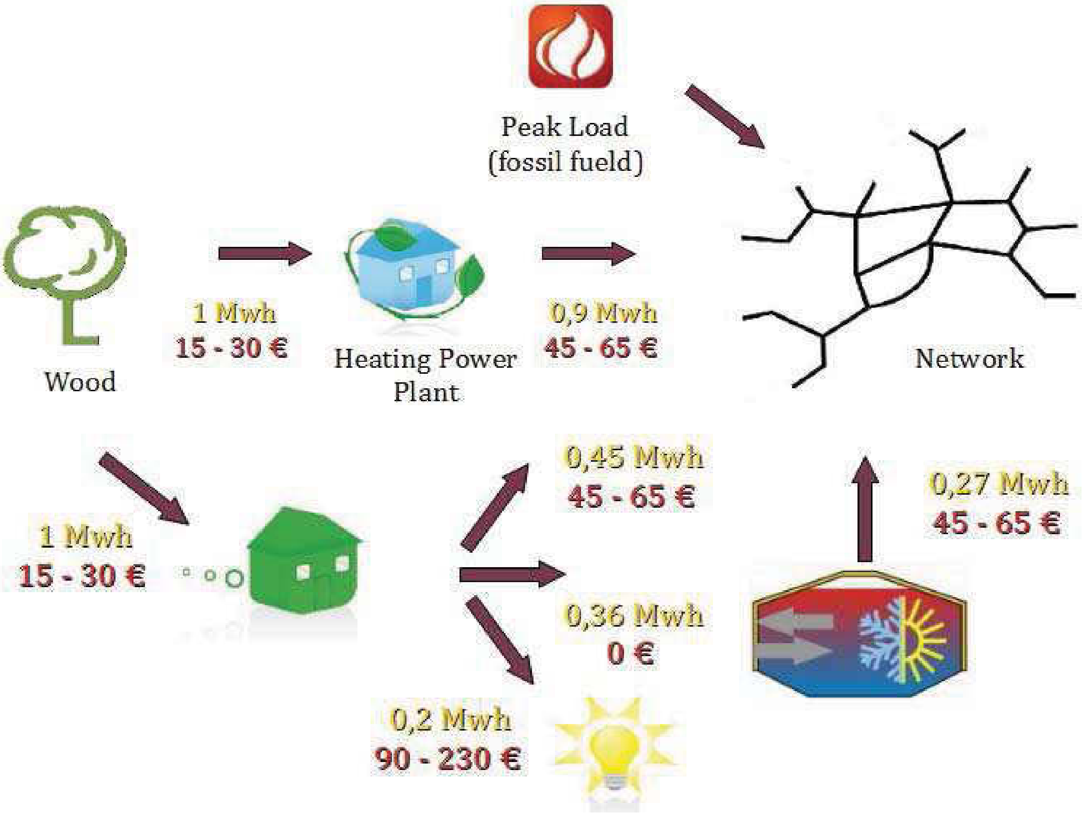


Figure 176 *Basic idea of a thermal storage utilized in a CHP project.*

Already existing: heating power plant; distribution network and peak load supply – Added: CHP Unit and thermal storage to take heat in times of low demand.

16.12.3 Assumptions

Demand Line

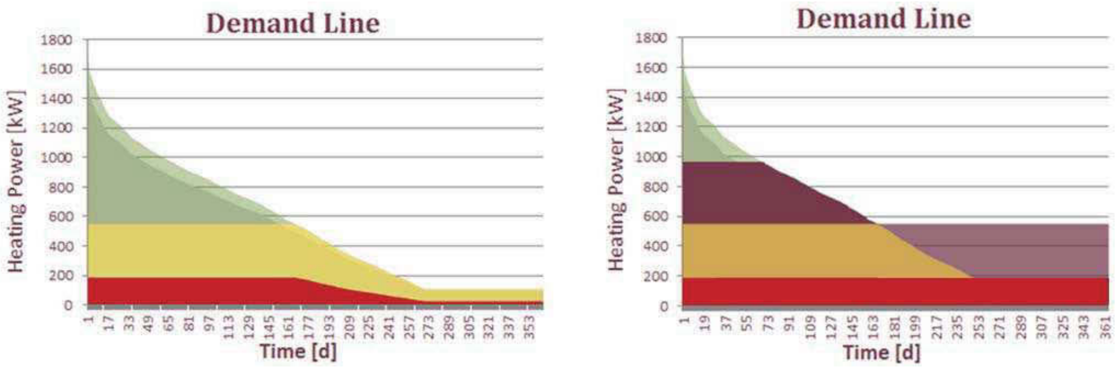


Figure 177 *Assumed demand line and straightened demand line*

Green = Heating power plant; Yellow = CHPU; Violet = Storage; Red = Electricity Production

Economic conditions

Fuel Price:	25 €/MWh
Heating Energy Price	55 €/MWh
Federal Electricity Support	180 – 190 €/MWh (based on federal support G.)
Operation Costs	0 €/y (-> unknown)
i:	10 %
D:	15 years

Facilities

Electric Efficiency:	25 % (Wood gasification)
Thermal efficiency:	90 %
Offline hours:	500 h/year
Storage Efficiency	70 %

Part Load Behaviour according to Figure (ORC)

Utilized Storage Temperature: 60 °C

Backflow Temperature: 30° C

Total heating demand is covered by heating power plant CHP unit and Storage – no peak load considered.

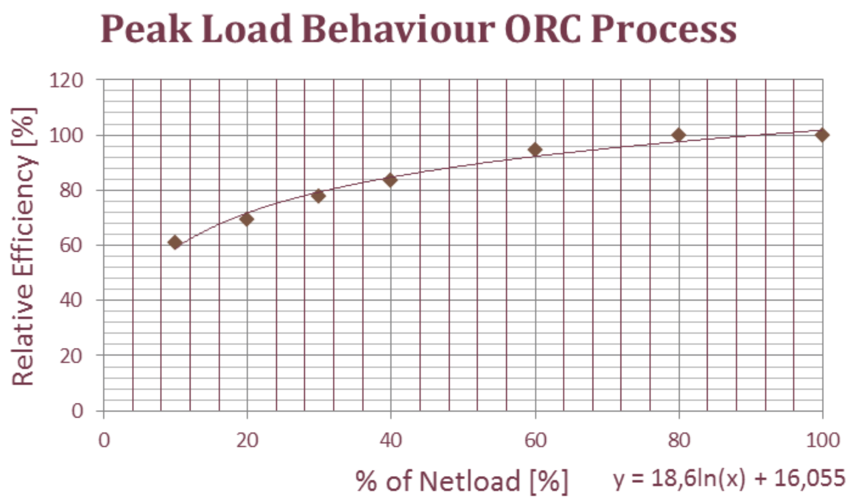


Figure 178 *Typical part load behaviour of an ORC process.*

The ORC process is known to have good part load behaviour therefore it was chosen to be on the safe side, when evaluating revenues without thermal storage

16.12.4 Evaluation

To evaluate the assumed scenario four cases were evaluated.

1.) Without any investments – heating power plant only
2.) Installing a part load driven CHP Unit
3.) Installing a full load driven CHP Unit (not a realistic case – as it wouldn't be supported)
4.) Installing a full load driven CHP Unit utilizing a thermal storage

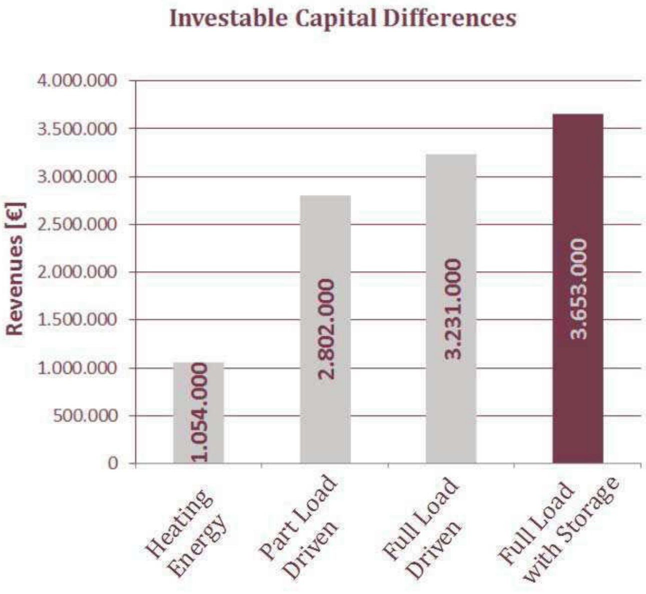


Figure 179 *Investable Capital for the four discussed cases*

Interesting to compare with each other is especially the case “Part Load Driven” and “Full Load with storage” as it shows the potential value of a thermal storage system. In the assumed case this would be approximately 800.000 €.

Also considerable is the difference between the case “Heating Energy” and “Part Load Driven” as it gives an idea of the value of the CHP unit in general, in this case this would be 1.800.000 €.

However it has to be considered that both values do not consider operation costs (as there is no reliable data), and assume very high online hours per year over a project life time of 10 years. Additionally also the electric efficiency of 25 % is on the upper border.

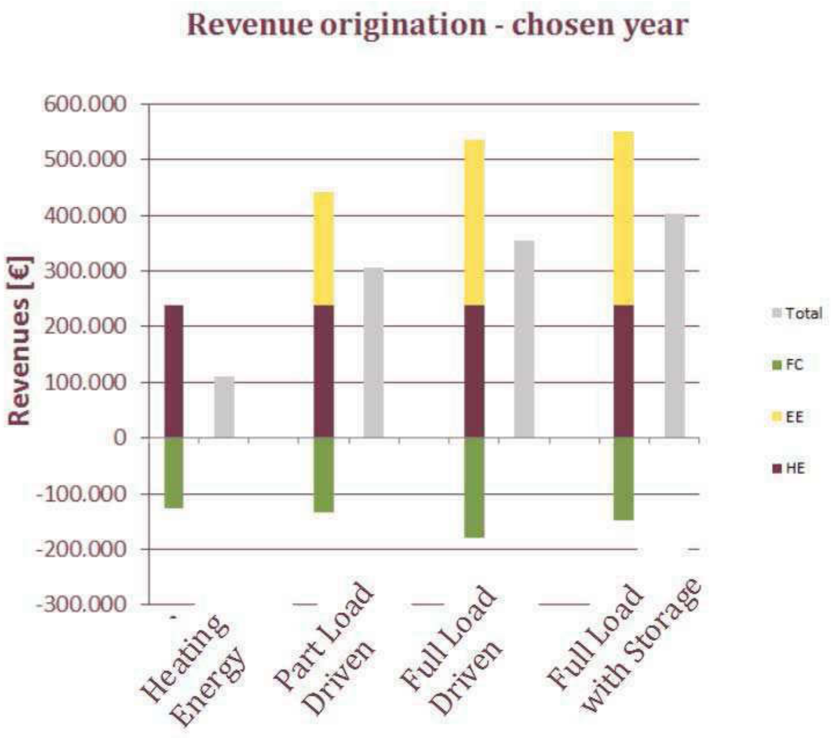


Figure 180 *Revenue origination and Revenue [€/y] differences for the four discussed projects.*

Silver: Revenue differences; Green: Fuel costs; Yellow: Revenues from Electric Energy; Violet: Revenues from Heating energy

Figure 180 *Revenue origination and Revenue [€/y] differences for the four discussed projects.*

Silver: Revenue differences; Green: Fuel costs; Yellow: Revenues from Electric Energy; Violet: Revenues from Heating energy reveal that revenues from electric energy demand are not as dominant as they are for biogas facilities. But they can be increased considerably for heating demand curves like assumed – which should be typically for demand lines dependant on home heating systems.

Additionally it is shown, that the dependence on fuel prices is lowest for the “part load driven” case slightly higher (depending on storage efficiency) for the “full load with storage”, and highest in the “full load driven” case.

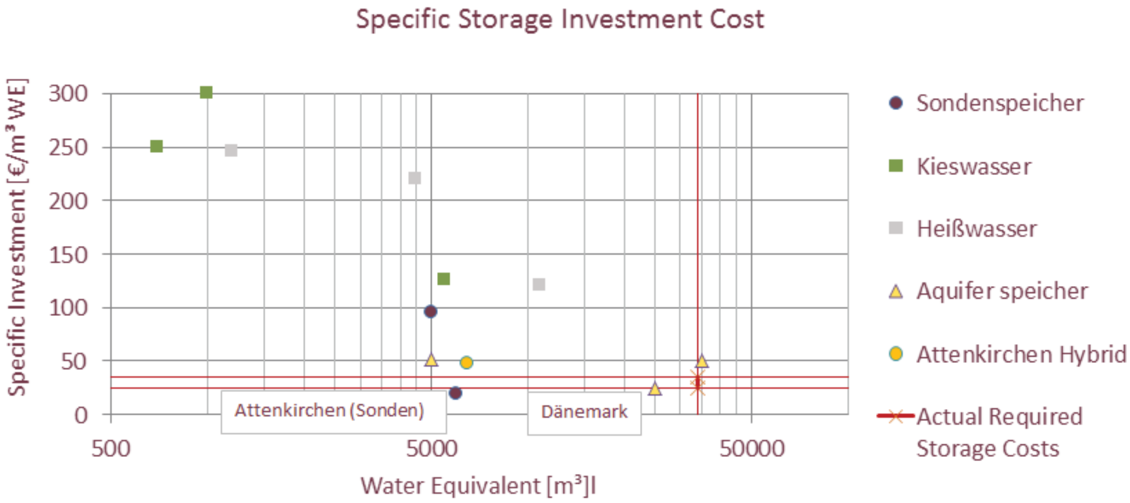


Figure 181 *Storage costs per water equivalent for various storage types and allowable storage costs per water equivalent for the assumed case.*

The red Lines mark the allowable investment cost range for the storage system, if it has to achieve the same internal rate of return as the CHP Unit itself Violet: BTES; Green and Grey: Tank storage systems; Yellow triangle: ATES, Yellow circle: Attenkirchen (Hybrid)

16.12.5 Conclusion

Under the given assumptions (i= 10% D= 15 y) a storage system is already in the range of realized projects without own federal support. If the CHP technology improves in terms of achievable online hours, reduction of operation costs and electric efficiency, it might be that there is a market for cheap and efficient thermal storage systems in future.

16.12.6 Conclusion thermal storage systems – from Drillers point of view

There might easily be a market for cost effective low Temperature thermal storage systems, now and in future. The lowest investment costs are offered by the aquifer storage system. From the drillers point of view this means, that cost effective drilling of relatively shallow exploration wells and production wells (<500 m) is required.

Additionally of course development of measuring tools and adaption of reservoir simulation tools would be required.

17 Electricity storage

17.1 General

This project type is a special case and differs from all other, because there is no heat energy sale involved. Additionally not all of the required technique is yet developed to the stage of market maturity. These are the reasons why this project type cannot be evaluated by the software. For the sake of completeness however a short technical description and some basic statements will be made.

The technique is also referenced to as CAES (compressed air energy storage)

17.2 Basic concept

The idea is to use subsurface cavity (e.g. caverns or old mines) or pore space (e.g. produced gas reservoir) to store compressed air in times of electric energy over hang. This compressed air is directed via a turbine to produce electricity during times of demand.

17.3 Technical problems

Major technical problems arise from temperature, during compressing the air is heated up causing stability problems. During expanding the storage air, cooling down results in water and gas ice particles falling out within the turbine. To avoid this, facilities of the first generation burn additional natural gas in the turbine (Huntorf G). Second generation facilities store the heat during compression and utilize it during expansion for preheating. Additional it is tried to keep the pressure during de charging constant by flooding the cavern.

17.4 Set up

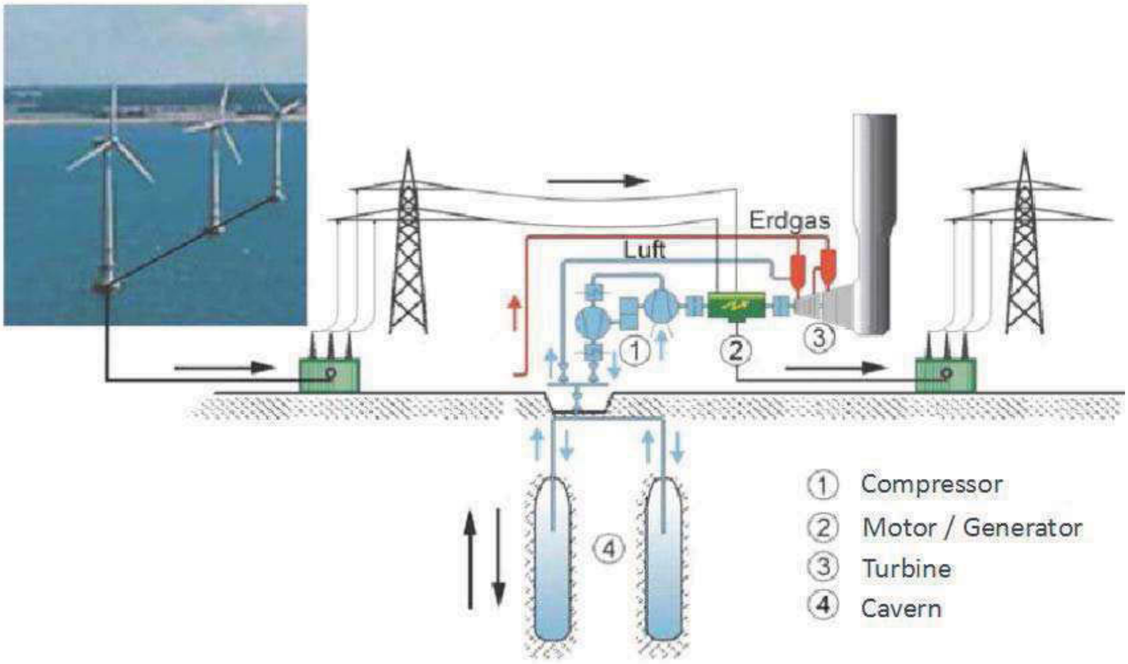


Figure 182:*Set up of a first generation CAES power plant. [24]*

17.5 Facilities and efficiencies

The first energy storage of this kind was built 1978 in Huntorf North Germany. The power plant has a net energy output if 320 MW for two hours.

To produce 1 kWh of electrical energy 0, 69 kWh of electric compressor work and 1, 17 kWh of natural gas has to be invested, resulting in an efficiency of 50 %

The best known modern CAES facility is built in Ohio USA, by Norton Energy Storage. An abandoned chalkstone mine will serve as storage. The final net output shall be 2500 MWh produce able for 48 hours. Due to the described heat storage system no additional natural gas will have to be burned resulting in an efficiency of 70 %

17.6 Economics

Electric power plant storages can be utilized in combination e.g. with a wind park, however at the actual politic situation in Austria and Germany offering guaranteed buy off of electric energy there is no demand. Another possibility is to store cheap energy in times of low demand and produce during expensive peak load periods, as it is done by water pump storage power plants. The water pump storage power plant market is generally considered as very good, leading to today situation where nearly all possible locations are already developed. (Concerning amount of energy, there is still considerable potential concerning power)

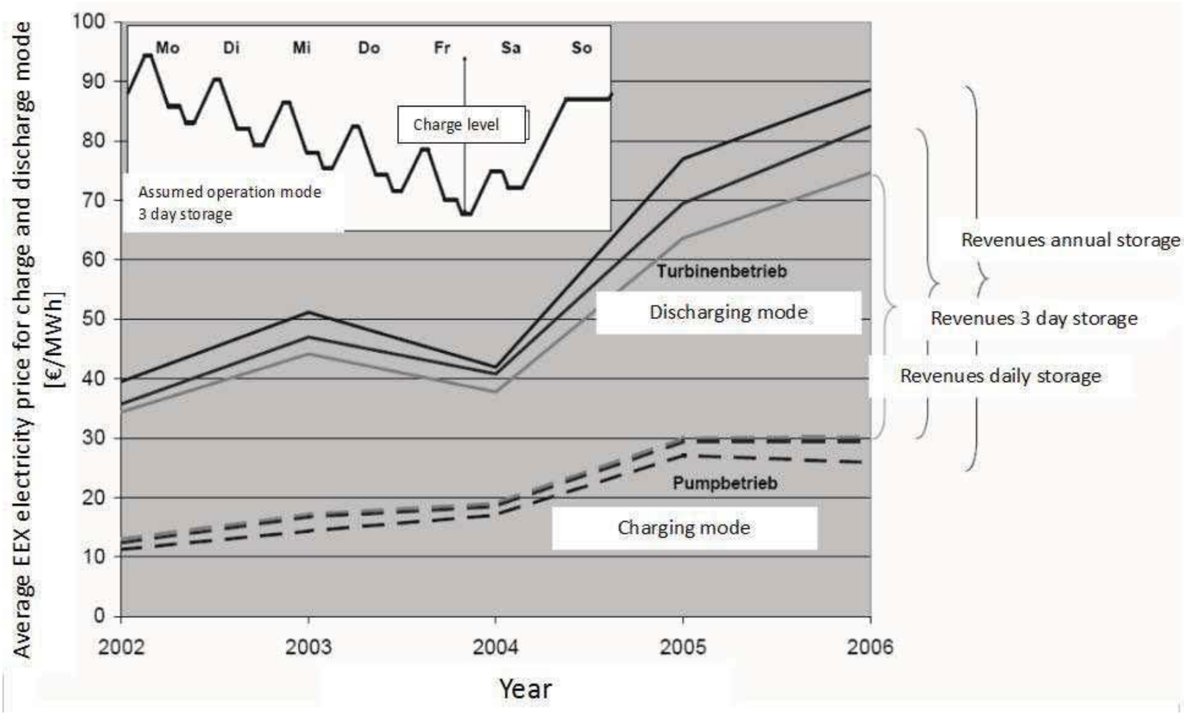


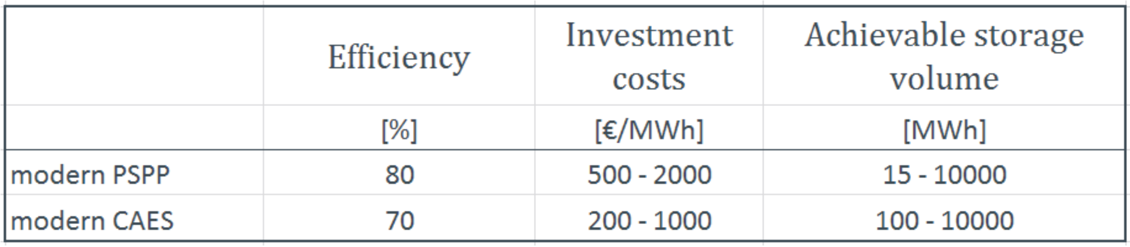
Figure 183 *Optimal electricity storage size [25]*

Figure 183 is the result of a study concerning the optimum size of pump power plants (regarding economics), it can be seen clearly, optimum size of an electric storage system is somewhere between daily and 3 day storage systems.

Which would mean, that also an optimum ATES storage system would be most likely designed for high power output. Taking into account the known demonstration and pilot projects from a drilling engineer's point of view it is an educated guess, that cheap large diameter drilling in relatively shallow depth (> 300 m) would be required.

The question is if the CAES storage technology is able to concurrence.

Comparison



	Efficiency	Investment costs	Achievable storage volume
	[%]	[€/MWh]	[MWh]
modern PSPP	80	500 - 2000	15 - 10000
modern CAES	70	200 - 1000	100 - 10000

Figure 184:*Comparison of PSPP and CAE storage system [data from 24]*

PSPP = Pump storage power plant

The actual market consists of a few running power plants and research projects. Experts believe that until 2020 10 to 20 facilities might be constructed. The total market volume was announced to be approximately 2 Billion (2*10^9). €. For further information the original literature is referenced “Umweltpolitische Innovations- und Wachstumsmärkte aus Sicht der Unternehmen”

Future will reveal if the concept will be successful, in Europe especially the company ALSTOM, takes effort to implement the technology

18 Final conclusion and recommendations

18.1 General

There are various possibilities for an oil and gas company to take part in the renewable energy sector. Utilizing core competences like knowledge about geology, exploration, drilling-, reservoir-, and production engineering.

Additionally middle European oil and gas companies are generally in very good economic condition, and in lack of promising prospects or projects to invest capital.

18.2 Actual situation from the author's point of view

18.2.1 Geothermal electric energy

At the moment most (in the Renewable Energy Sector) petroleum engineering equipment and capital is invested on large scale geothermal wells intending to produce electricity. According to the author's opinion, based on the investigations, these projects have some serious draw backs. Most significant is probably the extremely poor total and especially net electric efficiency, resulting in unattractive economics combined with serious risks, concerning unsure production rate and temperature, unforeseen early communication between production and injection well and unexpected drilling costs, to mention just the more important ones. Additionally the potential is very low, as fitting geology and heat energy demand is required, therefor it is expected that companies will drill only a relatively low number of these wells, if ever. Definitely not enough to climb down the learn curve or implement new technologies to save costs. Another serious disadvantage is that these projects are extremely dependent on federal support, at least 50 % of the revenues originate directly from the state, also investment support, cheap credits and insurances have to be granted. In other words, there is no realistic chance that such projects will ever come along without federal support. In the authors opinion politic will sooner or later recognise, that those projects are not worth to be supported. This day will for sure destroy all efforts done in research and development for these projects. Summing up all facts, I would recommend to completely stopping putting effort in this kind of projects.

The idea to use geothermal heat to spare feed water pre heating energy in fossil power plants, yielded surprisingly good results in a first estimation. However it has to be considered, that the authors background is drilling engineering. If this concept is applicable and economic should be judged by experts.

18.2.2 Geothermal heat supply

Second most effort is done to drill large scale geothermal wells for heating energy supply. These projects offer a good efficiency and a reasonable and clean usage of resources. Unfortunately very large amounts of heating energy need to be sold to balance the high investment costs for the bore holes and network. Resulting in a very low potential as fitting geology and a considerable demand are necessary. Additionally these projects offer relatively bad economics, as the building up of a large network delays revenues considerable. Another point is that the main challenge concerning these projects is heat energy customer acquisition and network construction, which are definitely not areas where RAG owns experience.

Nevertheless there might be circumstances where drilling of such wells can be interesting, but these are raw exceptions.

Serious effort was taken to investigate different sizes of (deep > 400 m) geothermal wells including combinations with various other heat sources (e.g. heat pump). However none promising broadly applicable project type was found. (These efforts are not documented in this work)

Interesting might be to split domestic water and heat energy demand with a double forward flow network. A shallow well could satisfy the low temperature heating, where as a small bio mass CHP covers the domestic water demand. This project type however would require a large row house settlement, applying cheap cellar to cellar distribution and a low temperature heating system. In other words: Ideal circumstances.

Deliberations to spare drilling costs by utilizing shallow wells, which energy is levelled up by a heating pump for broad application (> 60°C), did not yield satisfying results, due to too high investment costs, and additionally these sector is already occupied by specialised companies (which are to a considerable amount dependent on federal support of their projects, however are granted those and being therefore successful)

18.3 Most promising projects from the author's point of view

18.3.1 Heat storage

As discussed the author sees the highest potential in the development of heat storage systems. Actual circumstances seem to be especially favourable for a combination with biogas CHPs. This originates from the generous federal electric energy support and the increasing requirements on heating energy usage to achieve this. Additionally extra bonus is given if a large amount of waste energy is utilized.

A seasonal storage system could help to qualify for federal basic support or additional bonus on their electricity production. The potential can be considered as relatively high, there are more than 5000 biogas plants of fitting size online in Germany. There should be facilities which could profit from thermal storage systems. If other CHP technology will prevail for example wood (chips) fuelled CHPUs, an additional market might develop.

In comparison to large scale geothermal electricity production an advantage is the relatively small size of such projects, allowing a high and fast usage of the heating energy. Especially if a district heating system is anticipated. Naturally it can be assumed, that it is much easier and faster to manage convincing a high percentage of anticipated costumers in a project connecting about 100 objects than a few thousands. Appliance of investment cost saving measurements, such as special network or home station types are also more likely to be transcribed in a manageable small project.

Naturally also the investment costs are compare able low, approximately 30 to 40 medium to larger projects (Total costs) could be paid for the price of e.g.: one single geothermal electricity producing project nevertheless the net produced electric energy is in the same scale. (average net power / Investment Costs): Geothermal fuelled ORC: ~ 1, 5 MW / 70 Mio €; Biogas facility ~ 0, 5 MW/ 3, 5 Mio €)

Small projects size also allows justified hope to be able to climb down the learn curve, applying and experimenting with new techniques. However it should be considered that there is not an endless potential of free biomass, in fact a large part of the potential is already utilized.

As mentioned a good heat storing system would of course also be applicable to combinations with other heat sources e.g.: industrial waste- , solar-, heat pump-, other biomass energy.

The in the according chapter presented possible improvements of economics give justified reason for cautious optimism. Even though the development of applicable heat storage system is for sure not an easy task, it might be that investment and research work on this sector will pay back.

The possible local separation of biogas production and utilisation via an existing gas net is an interesting option offering various advantages. Further investigation should be done if the benefits surpass the additional losses and costs. First estimations yield a (slightly) positive result concerning the economics. Other discussed advantages cannot be doubt.

Regardless which of the described storage systems would be used, from the drillers point of view, cheap drilling technology for relatively shallow depth (0 ~ 750 m) exploration, heat exchanger and producing/injection wells would be required

18.3.2 Electric energy storage

The CAE storage system might play a role in future, in combination with wind parks and for electricity up valuation. Especially as the only concurring storage system, the water pump power plants have nearly exhausted their potential (Concerning energy not power). Major investments in the United States will lead to technology available on the market in the year 2015 that allows energy storage at an efficiency of 70 %. [24]

Future will reveal if this technology will prevail.

Especially for RAG, which has major experience in gas storage business, it might be interesting to further investigate this technology on its potential.

18.4 Fulfilment of set targets

The target was to identify projects in the renewable energy sector including petroleum engineering technology, which economics are good enough to be real concurrences to oil and gas projects, and are applicable in a wide range.

This target was most probably failed. Even if the combination of geothermal energy and a fossil power plant, works out as expected by the author, the achievable economics actually would achieve a draw level, but due to the expected few possible locations such a project would be exotic.

The second identified economically interesting project type, the combination of heat storage and bio gas CHP units (e.g.: as described for a pilot project in Section 2), would be apply able on a relatively big scale. However, even though the achievable economics are not that bad, they are for sure far behind a classic oil or gas prospect. If at all a fitting storage type can be developed.

Nevertheless the thesis had some interesting outputs, including the evaluation software. (Which was not really stretched for this thesis, as no real case study was done, and all calculations were done in the rough estimation mode). Maybe in my future work life I can enhance the applied functions and calculations further to gain really rigid data. Furthermore I am going to have the chance to investigate in a first step if a pilot heat storage system is reasonable to be constructed in a pilot project. The pre investigations of this project will be presented in the 2nd part of the work

18.5 General situation of the renewable energy market from the author's point of view

In the author's opinion, there is very little chance, that we will be able to handle the uprising energy crises. Even in a country like Austria, that is blessed with available water craft energy the contribution of renewables, especially concerning high quality energy such as electricity and fuel is still shocking low. Maybe a system, where after all just one number – the internal rate of return – counts, is not able to react in an appropriate manner. Trials of the state to steer against the development with federal support and other incentive are seldom done in the most useful way. In addition this assistance is exploited by nefarious companies and lawyers, who will always prefer a technically and ecologically senseless concept to a reasonable one, if just the internal rate of return fits - no matter how it is achieved.

In my personal opinion some federal support is nothing more than a present to the industry, diverting tax payer's money in the right pockets, masked as ecological measurement, in reality however destroying irreplaceable natural resources.

In sake of not leaving the last words of this part of the thesis to pessimism, it is also stated, that there have been a few projects realised, in which really good engineering work was performed, yielding to promising results such as to mention one the impressive project in Attenkirchen, giving hope and inspiring for further work that needs to be done.

Section 2

Pre Investigations -
Thermal Underground Storage
at the Biogas Facility Schwarzmayr"

Supported by:
ADS/TDE Advanced Drilling Solutions

ADS
Advanced Drilling Solutions GmbH

19 Target

Target was to identify a fitting project type, based on the results of the first part of this work. Fitting in this case referred to favourable conditions concerning

1.) Economic
2.) Facility / Storage technic (required power, temperature levels, etc.)
3.) Geology
4.) Storage technic

Economic

It should be tried to find an existing facility in Austria, where the construction of a storage system would improve the economic in two ways. First qualify for additional electricity support and secondly improve the value of heating energy.

Facility / Storage technic

Especially important is the possibility of using energy on an as low Temperature level as possible. Additionally it is important, that the additional energy can be brought into the system without major investment. As well as required power output, storage time between charging and discharging and required size are important factors

Geology

Geology should be explored (+ published data) by nearby wells. Favourable for aquifer storage system would be a clay sand clay section without (or very little) ground water movement. Also important are heat storage capacity (mainly dependant on water content/porosity), and aquifer geometry and depth.

20 Pilot project: Biogas CHPU “Schwarzmayr”

20.1 Project overview

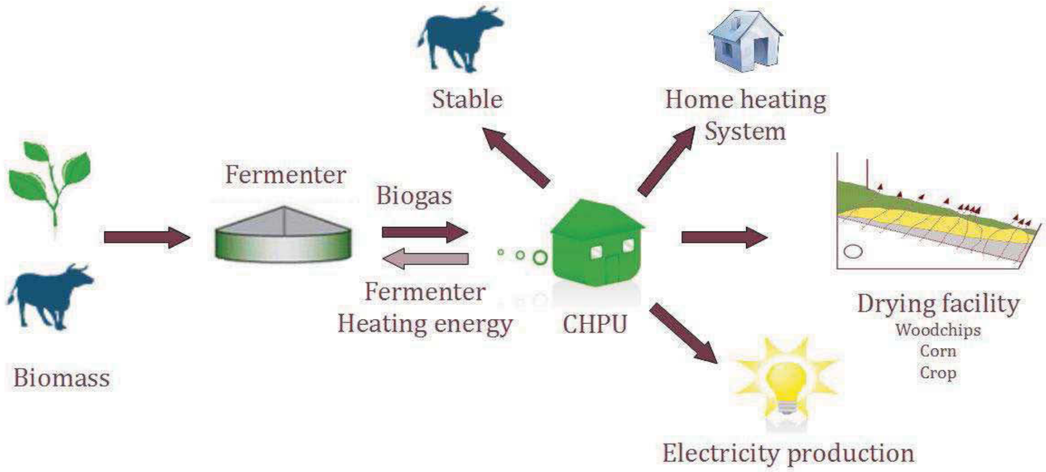


Figure 185 *Illustrated is a scheme of the existing facility [own illustration]*

The fermenters are fuelled with liquid manure and corn, biogas is transferred to a CHPU (Otto motor), which delivers an electric power of 330 kW and a heating power of approximately 400 kW. The electricity is sold to the net owner by a predefined federal supported price. The waste heat is mainly utilized for two drying facilities which are used on wood chips, corn and crop, additionally home and stables are heated.

20.2 Waste energy useage

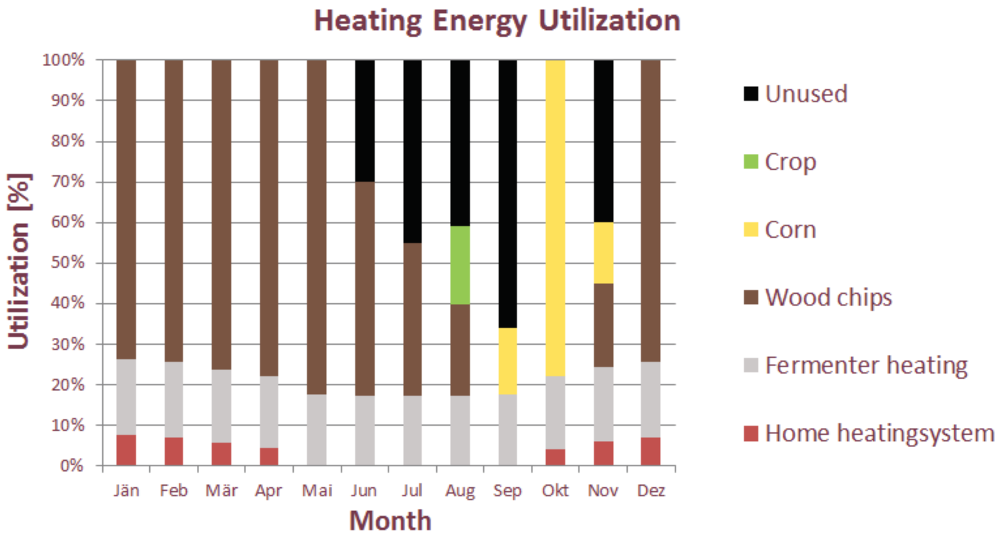


Figure 186 *Heat Energy Utilization in percentage of total waste heat. [Own illustration]*

Figure 188 was drawn according to information provided by Josef Schwarzmayr (facility owner). The drying facility demand was directly taken from this information. The home heating system demand was adjusted to the regional climate data, as well as the fermenter heating was. (However imbued with a dampening factor, due to the fact that it is constructed subsurface)

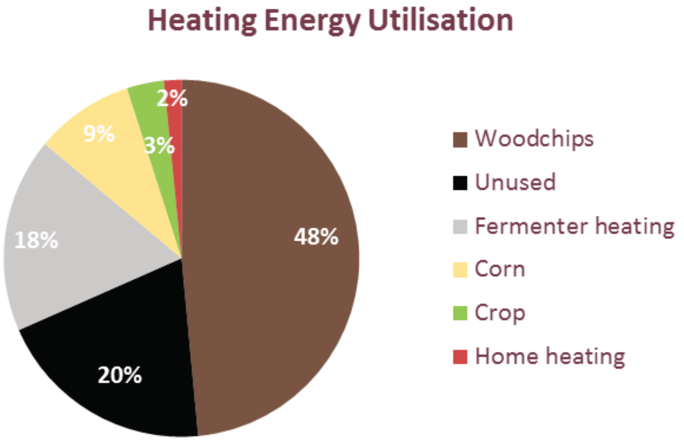
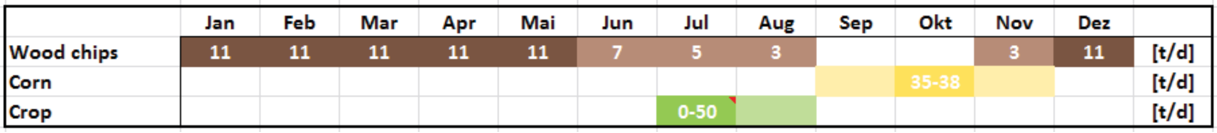


Figure 187 *Total heating energy utilization in per cent [own illustration]*

20.3 Waste Energy utilization economics



	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez	
Wood chips	11	11	11	11	11	7	5	3			3	11	[t/d]
Corn										35-38			[t/d]
Crop							0-50						[t/d]

Figure 188 *Drying facilities output in [t/d] (of dried bulk) Corn 6 – 8 weeks in September – November; Crop 0 – 1 week in July – August [own illustration]*

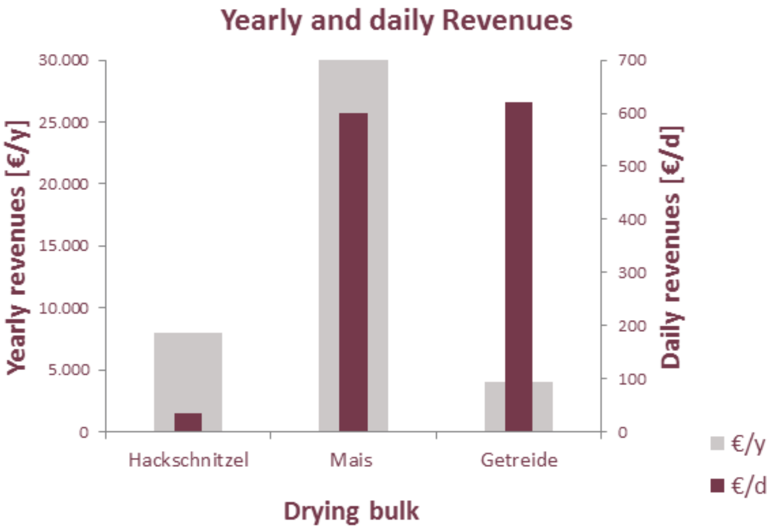


Figure 189 *Daily and typical yearly profit (50 days of corn drying season and 7 days wheat drying season assumed) [own illustration]*

20.3.1 Comments to the most important heating energy demanders

Woodchips

As demonstrated in the illustrations, woodchip drying takes the major amount of waste heat energy (almost 50 %). The creation of value is rather low, economic sense is given on the one hand, as the heating energy usage qualifies the facility for federal support, on the other hand of course because the heating energy is free.

The woodchip drying capacity can normally fully be used during winter times, during spring and summer farmers usually do not have time to bother with low lucrative woodchips. Therefore the demand drops rapidly after May, especially during phases of weather favourable for other farmers work.

Woodchips Eeonomics (rough averaging)

Drying price:	~ 3150	€/full capacity month	(= ~ 330 t)
Personal/Machine	~ 1350	€/full capacity month	(= ~ 30 h)
Electricity demand	~ 100	€/full capacity month	
Depreciation	~ 160	€/ full capacity month	
Revenue before taxes	**~1540**	**€/ full capacity month**	
Taxes (15 % gross income)	~470	€/ full capacity month	
Revenue	**~1070**	**€/ full capacity month**	

Corn

The corn drying season is 6 – 8 weeks scheduled between September and November, depending on the corn growing conditions of the year. Even though corn drying just takes a rather small amount of the total heating energy (approximately 10 %) it delivers 250 – 450 % of the total drying revenues.

Corn economics (rough averaging)

Drying price:	~ 24000	€/full capacity month	(= ~ 1100 t)
Personal	~ 2000	€/full capacity month	(= ~ 90 h)
Electricity demand	~ 350	€/full capacity month	
Depreciation	depreciated		
Revenue before taxes	**~** 21650	**€/ full capacity month**	
Taxes (15 % gross income)	~3600	€/ full capacity month	
Revenue	**~** 18050	**€/ full capacity month**	

Crop

The crop drying season is 0 – 7 days scheduled in July – August. It is only necessary in case of bad weather and often drops completely out, therefore it is not further considered.

20.3.2 Qualification for “KWK Bonus”

In a good year, assuming 50 days of corn and 7 days of crop drying the facility can utilize approximately 80 % of its waste heat. As described in Section 1, to achieve the KWK Bonus in Austria following equation must be valid

$$\frac{2 * E_{heat}}{3 * E_{fuel}} + \frac{E_{electric}}{E_{fuel}} > 0{,}6$$

Equation 35 *“KWK Bonus” criteria*

According to calculations of Mr Schwarzmayr this requirement could be met if approximately 300 MWh of additional heating energy could be utilized (~ 10 %).

The calculation is not done here as it is rather complicated and would require insight into details of the concerned law and appliance of it. (“Kraftwärme Kopplungsgesetz”)

20.4 Anticipated economical improvements utilizing a thermal storage

Obviously the idea is to take energy from times of low demand in summer store it to use it during the corn drying season in fall.

20.4.1 Desired effects and energy amount

1.) Qualification for “KWK Bonus”	~ 300 MWh additional energy use
2.) Double Corn drying capacity	discharge and use~ 300 – 400 MWh
3.) Avoid the usage of peak load oil	up to 100 MWh
4.) Providing buffer capacity	

Comment desired effect 1

The qualification can be achieved if the additional energy is used “in a reasonable way” as formulated by the legislator. As this project would be the first of its type in Austria, “reasonable” is not clearly defined yet.

Does energy count as reasonable used if it is used for storage charge, it is discharged or the amount of used energy is calculated by the additional achieved drying capacity.

As an engineer, the author would of course prefer the last possibility at it is sensible to the true value of the project.

As an investor or salesman it of course would be favourable if already the charging process counts as “reasonable” use, if possible also for testing purposes to absorb risk.

However at the moment it is tried to achieve this by lobbying and through litigation at least for this pilot project, but a decision has not been made yet.

Comment desired effect 2

The rather large distribution of required energy originates from different drying season lengths.

Comment desired effect 3

During very cold or wet weather it might be necessary to additionally heat with oil. This would be avoided in a very elegant way, as the stored energy is automatically levelled up if the outside temperature drops, due to the larger usable temperature difference.

Comment desired effect 4

The ability to shift woodchip drying capacity to bad weather periods by providing an approximate two week buffer will help to achieve the required woodchip capacity or even increase it. Additionally Mr Schwarzmayr wouldn’t be forced to spent valuable working time on wood drying in times where his working power is required on other activities.

20.4.2 Desired Effects – Economic Value

1.)	Qualification for “KWK Bonus”	~ 60.000 €
2.)	Double Corn drying capacity	~ 27.000 – 36.000 €
3.)	Avoid the usage of peak load oil	~ 9000 € (average)
4.)	Providing buffer capacity	not quantified

A storage system fulfilling all requirements would therefore **additionally** yield approximately **100.000 €/year (~ ca. 800.000 € assuming PD=10 [y] i= 5 [%])** before taxes and operation costs, which desired effects can be achieved will reveal.

The drying facility actually yields 30.000 – 45.000 €/y (in good years), this would equal an improvement of approximately 380 %.

20.5 Technical feasibility – Facility

In this chapter it shall be investigated if the corn drying capacity of the facility can be increased and if yes by which means. To answer this question the drying process has to be investigated.

20.5.1 Drying process – Facility set up

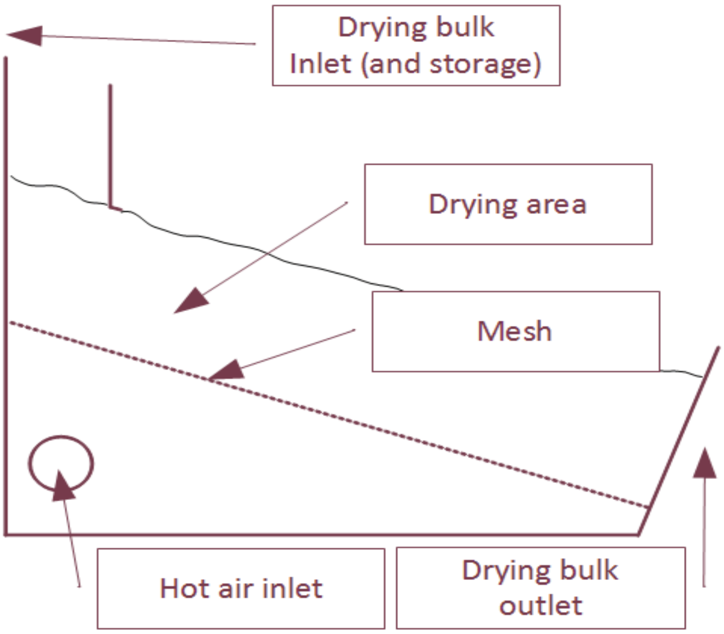


Figure 190 *Sketch of the container drying facility [own illustration]*

The drying facility type is “Container drying” air from outside is heated up and blown in the lower side of the container via ventilators, the hot air flows upwards through a mesh and further through the drying bulk, while doing this the water content is enriched, and therefore the bulk is dried.

It should be mentioned that the maximum Temperature is capped at 85°C, because above the corn would be destroyed (or more exact loose quality e.g. germination capacity)

20.5.2 Container drying process – Required energy – Thermodynamic principle

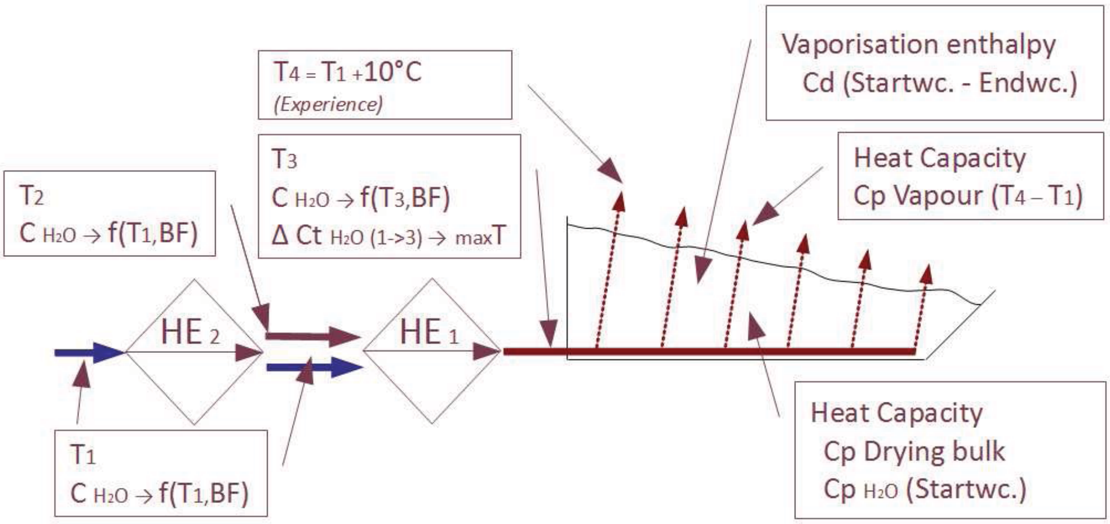


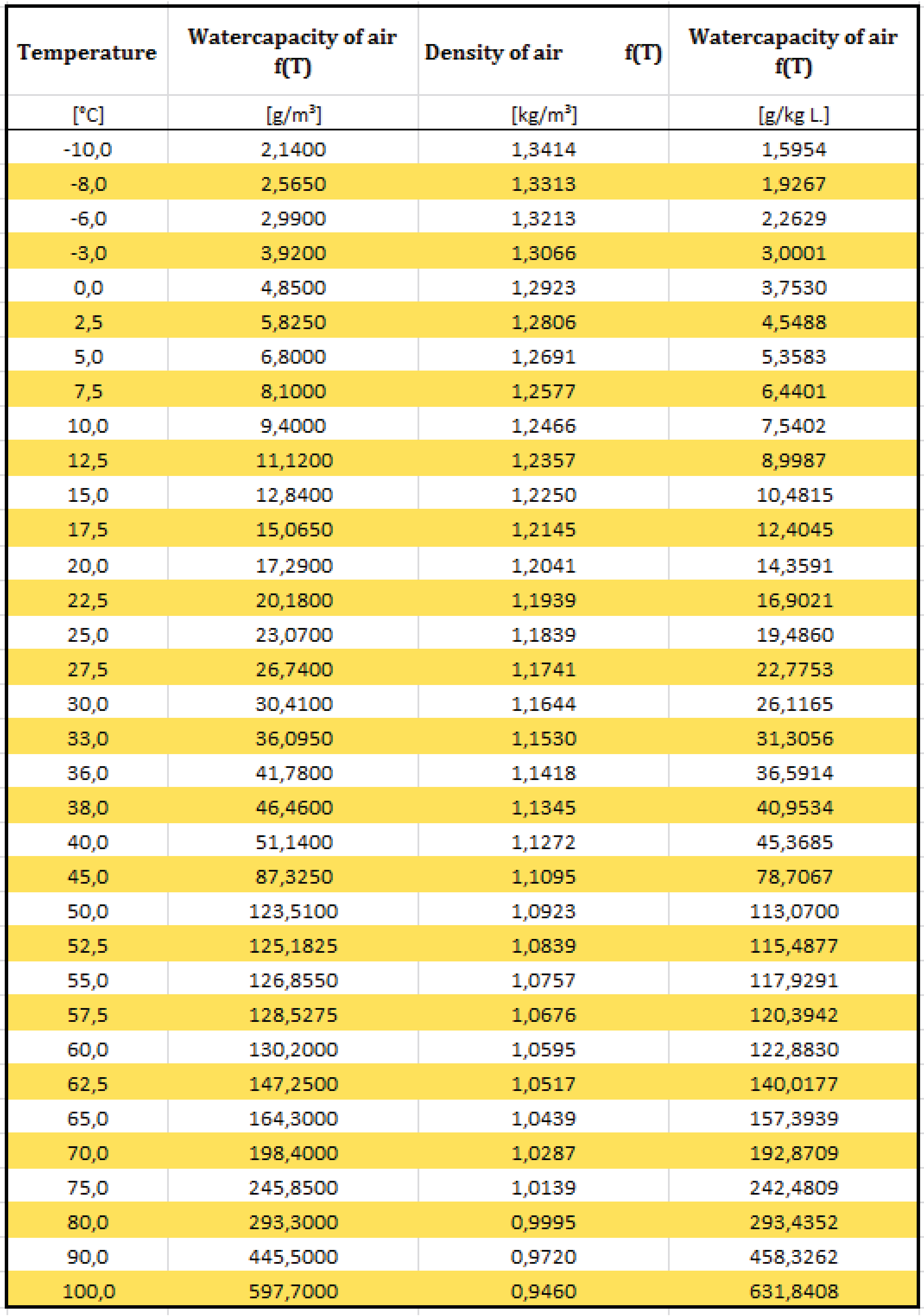
Figure 191 *Base for calculating required heating energy/power [own illustration]*

Figure 191 illustrates the most important factors for calculating the required heating energy/power. The required net heat capacity originates from three processes

1.) Heating up the drying bulk including water content
2.) Vaporise the undesired water content
3.) Remaining Energy in drying air (vapour)

p	T	v´	v´´	h´	h´´	r	s´	s´´
[bar]	[°C]	[m³/kg]	[m³/kg]	[kJ/kg]	[kJ/kg]	[kJ/kg]	[kJ/kgK]	[kJ/kgK]
0,0061	0,01	0,001	206	0	2500,9	2500,9	0	9,1555
0,01	6,97	0,001000	129,18	29,3	2513,7	2484,4	0,1059	8,9749
0,02	17,5	0,0010014	66,99	73,43	2532,9	2459,5	0,2606	8,7227
0,03	24,08	0,001003	45,66	100,99	2544,9	2443,9	0,3543	8,5766
0,04	28,96	0,0010041	34,79	121,4	2553,7	2432,3	0,4224	8,4735
0,05	32,88	0,001005	28,19	137,77	2560,8	2423	0,4763	8,3939
0,06	36,16	0,0010064	23,73	151,49	2566,7	2415,2	0,5209	8,3291
0,07	39	0,001008	20,53	163,37	2571,8	2408,4	0,5591	8,2746
0,1	45,81	0,0010103	14,671	191,81	2583,9	2392,1	0,6492	8,1489
0,2	60	0,001017	7,648	251,4	2609	2357,6	0,832	7,9072
0,3	69,1	0,0010222	5,229	289,23	2624,6	2335,3	0,9439	7,7675
1	99,61	0,001043	1,694	417,44	2675	2257,5	1,3026	7,3588

Figure 192 *Table of water properties used for calculation spread sheet [own illustration - according to data of 35]*



Temperature	Watercapacity of air f(T)	Density of air f(T)	Watercapacity of air f(T)
[°C]	[g/m³]	[kg/m³]	[g/kg L.]
-10,0	2,1400	1,3414	1,5954
-8,0	2,5650	1,3313	1,9267
-6,0	2,9900	1,3213	2,2629
-3,0	3,9200	1,3066	3,0001
0,0	4,8500	1,2923	3,7530
2,5	5,8250	1,2806	4,5488
5,0	6,8000	1,2691	5,3583
7,5	8,1000	1,2577	6,4401
10,0	9,4000	1,2466	7,5402
12,5	11,1200	1,2357	8,9987
15,0	12,8400	1,2250	10,4815
17,5	15,0650	1,2145	12,4045
20,0	17,2900	1,2041	14,3591
22,5	20,1800	1,1939	16,9021
25,0	23,0700	1,1839	19,4860
27,5	26,7400	1,1741	22,7753
30,0	30,4100	1,1644	26,1165
33,0	36,0950	1,1530	31,3056
36,0	41,7800	1,1418	36,5914
38,0	46,4600	1,1345	40,9534
40,0	51,1400	1,1272	45,3685
45,0	87,3250	1,1095	78,7067
50,0	123,5100	1,0923	113,0700
52,5	125,1825	1,0839	115,4877
55,0	126,8550	1,0757	117,9291
57,5	128,5275	1,0676	120,3942
60,0	130,2000	1,0595	122,8830
62,5	147,2500	1,0517	140,0177
65,0	164,3000	1,0439	157,3939
70,0	198,4000	1,0287	192,8709
75,0	245,8500	1,0139	242,4809
80,0	293,3000	0,9995	293,4352
90,0	445,5000	0,9720	458,3262
100,0	597,7000	0,9460	631,8408

Figure 193 *Water capacity of air as a function of temperature [own illustration - according to data of 35]*

1.) Heating up the drying bulk and original water content

This is calculated by according heat capacities and Temperature difference between outside and drying temperature.

$$E_I = (cp_{water} * m_{water} + cp_{bulk} * m_{bulk(dry)}) * (T_4 - T_1)$$

Equation 36 Energy required heating up bulk and original water content

E [kJ] (Energy); cp [kJ/kgK] (heat capacity); m [kg] (mass); T [K] (Temperature);

(The spread sheet uses the values: Corn: 1,296 [kJ/kg K]; Woodchips 1, 9 [kJ/kg K]; Water 4,186 [kJ/kg K] ;

2.) Vaporisation of undesired water content

Calculated by using water content difference between start and end value and according vaporisation enthalpy.

$$E_I = (wc_{start} - wc_{end}) * m_{bulk} * cd_{water}$$

Equation 37 Energy required vaporising undesired water content

E [kJ] (Energy); wc [kg_{water}/kg_{total}] (Water content) cd [kJ/kg] (Vaporisation enthalpy); m [kg] - Numbers according to Figure 192 Table of water properties used for calculation spread sheet

3.) Remaining energy in drying air (vapour)

After drying air has passed the drying bulk and enriched itself with water it leaves the system taking remaining heat energy with it, as it does not cool down to outside temperature level. To calculate this amount of energy first the required amount of drying air needs to be known, which is a function of water capacity difference between outside (T_1) and inlet (T_3) Temperature (as illustrated in Figure 194) and the water difference between start and target water content.

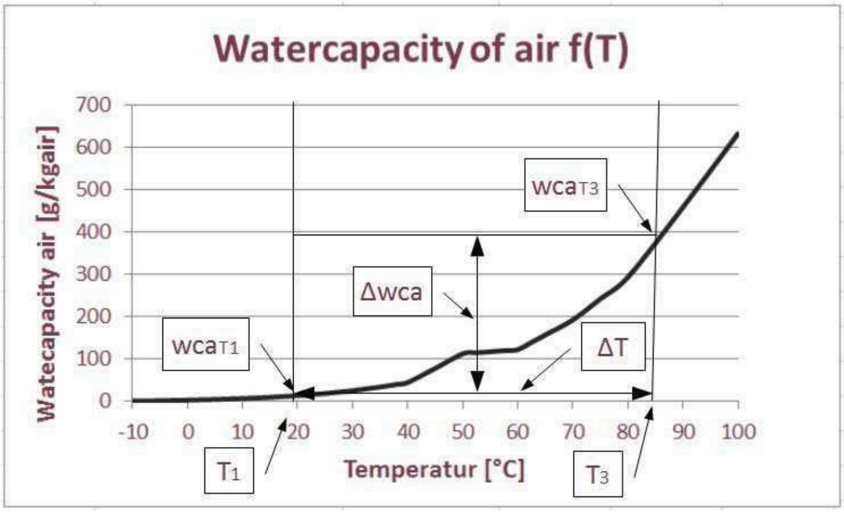


Figure 194 *Water capacity of air as a function of Temperature*

$$wca_{TI} = wca(T1) * RW_{air}$$

Equation 38 *Water content at inlet temperature*

wca [gwater/kgair] watercapacity; RWair [%] Relative wetness of air

$$\Delta wca = wca_{TI} - wca_{TI}$$

Equation 39 *Water drying capacity per kg air*

$$m_{air} = \frac{(wc_{start} - wc_{end}) * m_{bulk}}{\Delta wca}$$

Equation 40 *Required amount of drying air*

$$E_{III} = m_{air} * cp_{vapour}(T_1 + 10)$$

Equation 41 *Remaining energy in drying air (vapour)*

E [kJ] (Energy); cp [kJ/kgK] (heat capacity); m [kg] (mass),

Assuming the vapour temperature is a value based on experience, it might be wrong especially during times of very cold outside Temperature, the evaluation spread sheet shall be improved after measuring this temperature in the following drying season.

$$E_{total} = (E_I + E_{II} + E_{III}) * \eta_{CD}$$

Equation 42 *Total required energy (η_{CD} [] Container drying efficiency)*

The total required energy is as already discussed the three described energy consuming effects summed up, times a facility specific efficiency. (Which is temperature dependent, but the functions are no known yet, but might reveal during measurements in this year's season)

Importance of discussed factors – Corn

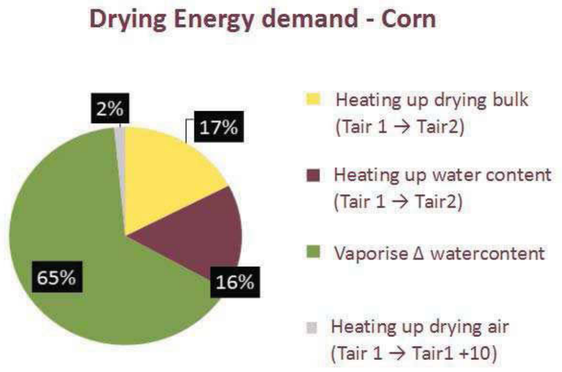


Figure 195 *Drying Energy demand corn.*

Assumed was a starting of 26 % and a target wetness of 14 %; further relative air wetness of 100 % and an outside temperature of 10 °C

Importance of discussed factors – Corn

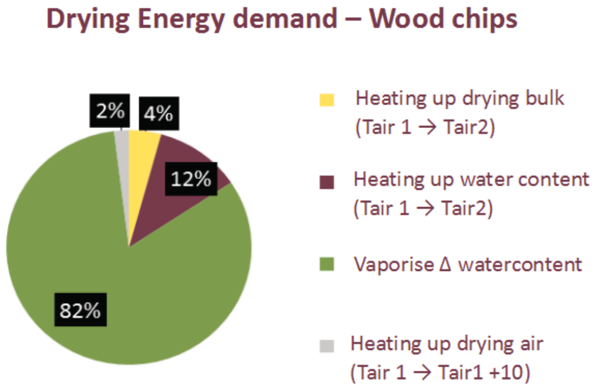


Figure 196 *Drying Energy demand woodchips.*

Assumed was a starting of 65 % and a target wetness of 30 %; further relative air wetness of 100 % and an outside temperature of 10 °C

In both cases the most important factor is the vaporisation of undesired water content. Also heating up total amount of water is an important energy consumer; therefore obviously the drying energy demand depends mainly on the starting and target water content. Heat capacity of the dry bulk plays a minor role.

20.5.3 Container drying process – Bringing (additional) energy to the system

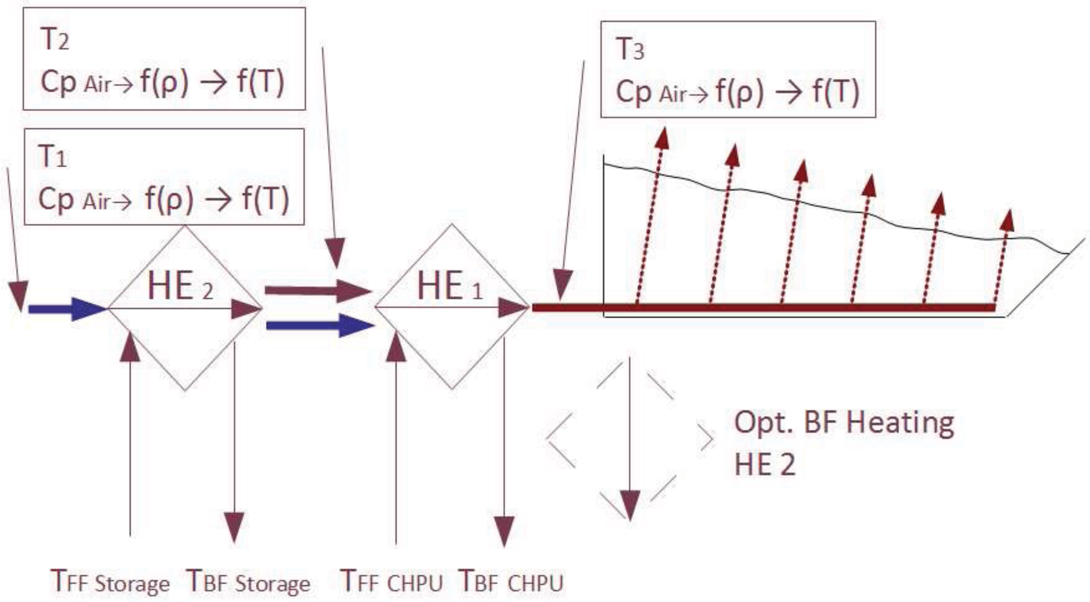


Figure 197 *Bringing (additional) energy to the system*

HE = Heat exchanger; FF = Forward Flow; BF = Back Flow; Cp = Heat Capacity; ρ = Density

As illustrated in Figure 197 the energy is brought into the system by heating up the inlet air via a heat exchanger fed by the CHP unit. To bring in additional energy from the thermal storage it would be possible to preheat the inlet air, as will be assumed further on. Another possibility would be to use it for preheating the CHPU'S backflow.

Temperature levels

$$T_{FF\ Storage} = T_1 + \Delta T_{HE2}$$

$$T_{BF\ Storage} = T_2 + \Delta T_{HE2}$$

$$T_{FF\ CHP} = T_3 + \Delta T_{HE1}$$

$$T_{BF\ CHP} = T_2 + \Delta T_{HE2}$$

Equation 43 *Temperature levels*

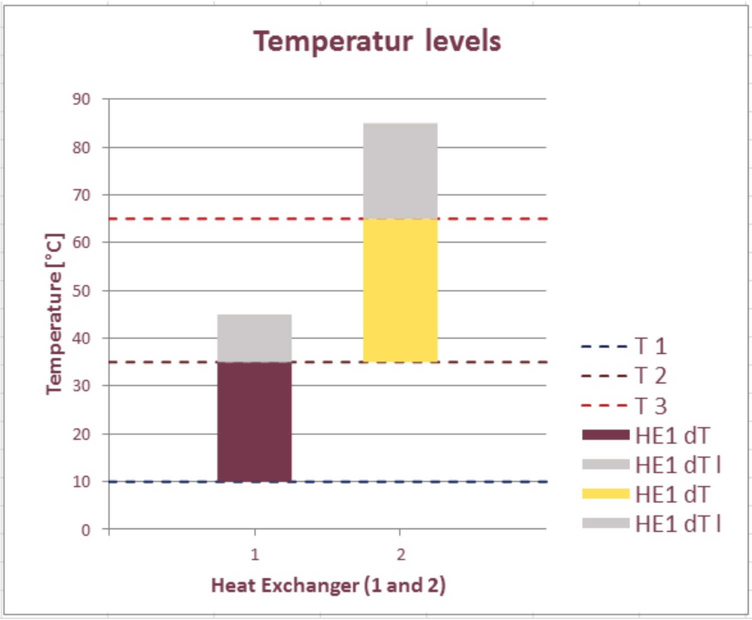


Figure 198 *Calculated temperature levels during corn drying.*

Assuming a CHPU FF Temperature of 85 °C and an drying air inlet Temperature of 65 °C; a storade decharging Temperature of 45 °C and an achieved air preheating Temperature of 35 °C at an outside Temperature of 10 °C (average value for drying season)

Heat exchanger ΔT = $T_{water\ inflow} - T_{air\ outflow}$ *(corresponding to the German term "Grädigkeit")*

Corn quality and maximum inlet temperature

It shall be mentioned; that the maximum inlet temperature is not governed by achieving as high drying performance as possible, but achieving high corn quality is more important. Above certain temperatures and durations the corn is exposed to them it loose in quality. Without going into details, for this reason it is practice at the drying facility Schwarzmayr to use rather low Temperature levels < 70°C

Heating Power

According to the discussed Temperature levels of heating and preheating and the heat capacity of air as a function of Temperature the heating power that can be brought in the system by both sources – CHPU and Thermal Storage – can be calculated.

$$P_{CHPU} = m * cp_{air} f(T) * (T_{FF\ CHPU} f(T_3, HE_2) - T_{BF\ CHPU} f(T_2, HE_2))$$

$$P_{Storage} = m * cp_{air} f(T) * (T_{FF\ Storage} f(T_2, HE_1) - T_{BF\ CHPU} f(T_1, HE_1))$$

Equation 44 *Heating power of both sources (CHPU and thermal storage)*

According to this calculations the power distribution between the two providers – CHPU and thermal storage can be calculated for different outside and storage discharge Temperatures.

The additional brought in Energy allows an increase of the amount of drying air, which should in a first approach suggestion yield higher drying capacity

20.5.4 Container drying process – Corn properties and corn drying

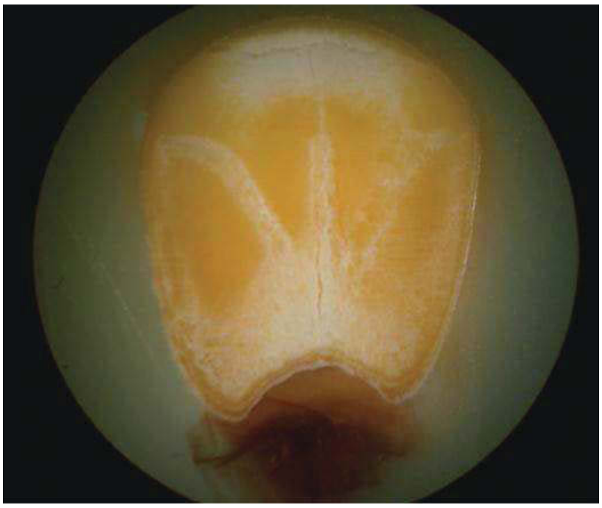


Figure 199 *Microscopic image of one corn [28]*

Figure 199 illustrates one corn, as can easily be imagined there are two main types of water within corn, one part covers the surface of the corn as a thin liquid film another part it situated in the capillaries inside the corn and of course inside the cells. With this imagination background the illustration describing the corn drying process is easily understood

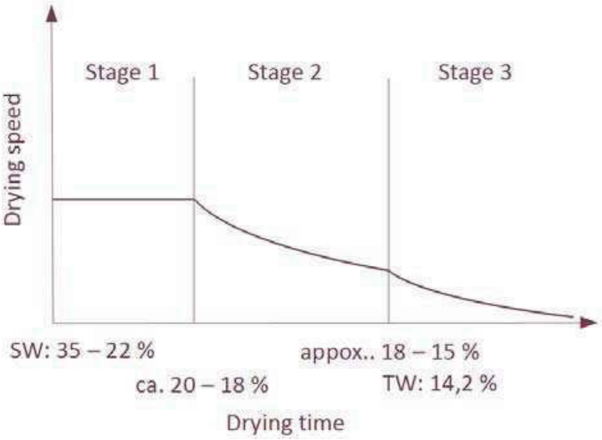


Figure 200 *Drying speed for air drying at constant air stream, drying stages and approximate wetness ranges. [Modified 28]*

(SW = Start wetness; TW= Target wetness)

Figure 200 illustrates a model of different corn (air) drying sections. In stage 1 the described liquid surface film exposed directly to the hot air stream disappears, it can easily be imagined that the drying speed is directly connected to the amount of drying air. (Or more exact the amount of lacking water content).

In the second and third section the water has to be transported via the capillaries or through the corn shell to the surface. (2nd and 3rd stage differ from each other due to the fact, that the importance of transport mechanism within the corn changes). For details original literature [28] and [29] is referenced.

However it can be stated that the drying process is not directly proportional to the amount of drying air anymore. Which draws up the question if, and how much the drying capacity can be increased by increasing just the amount of drying air.

To answer this question the total system has to be evaluated.

20.5.5 Container drying process – Expected results of increasing drying air stream

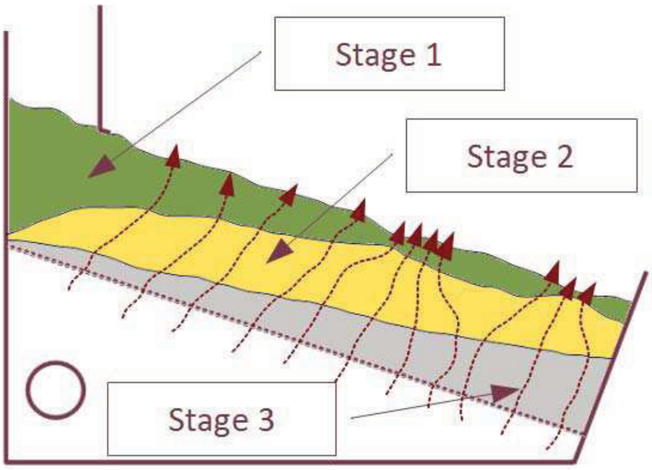


Figure 201 *Corn drying process within a container drying facility [own illustration]*

As illustrated in Figure 201 all three stages occur at the same time within one drying process. The corn at the bottom of the bulk might easily have reached stage 2 or 3 while at the top there is still a liquid film around the corns, and therefore being in stage 1.

However as long as the air has to pass by corn being in stage 1 the drying speed will be proportional to the amount of drying air at least there, which basically means, as long as the drying bulk is still covered with a layer of corn being in stage 1 it has the same effect as if the total system would be in stage1.

The homogenous spread of the section borders is an important point to guarantee a good efficiency drying. It can be supported if the corn is brought in as smooth as possible. As well it can be observed if there is any corn in section to at the surface, as the corn colour changes slightly. The corn than can be rearranged manually to achieve a complete coverage again.

It is a matter of experience to catch the right time to discharge the container; it is approximately if 10 – 25 % of the surface corn changed its colour indicating being in section 2.

Obviously the corn charge does not have a homogenous water content, as naturally the corn at the bottom is by far drier than at the top, to equalize this the corn is – still warm – mixed, and an equilibrium will be reached by natural processes, during storage time. [27]

20.5.6 Container drying process - Conclusion

Due to the discussed effects and processes within the container dryer it can be assumed, that an increase of the amount of air will be more or less direct proportional to the drying capacity.

This is backed up by information given from Mr Schwarzmayr, according to him the facility is older than the CHPU and was driven by heating oil before, laid out for the double amount of heating power. [27]

20.6 Ideal storage layout – Size and power

20.6.1 Required temperatures / Required power

After already having defined the target of increasing corn drying capacity and according to the previous investigations it seems reasonable to aim for doubling the capacity. One of the most important factors is the required Temperature to achieve this.

As the required power is dependent on the outside Temperature climate data is required.

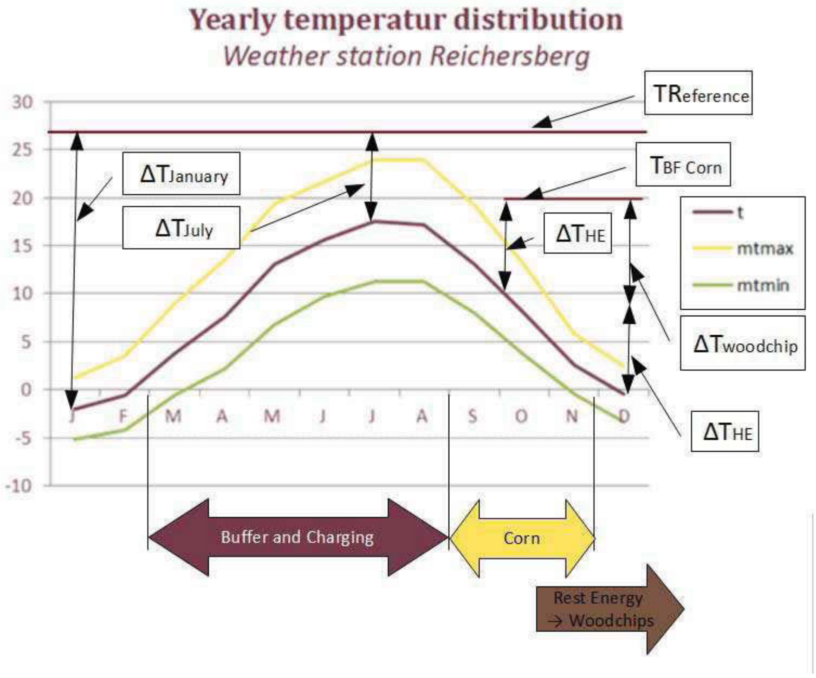


Figure 202 *Climate data weather station “Reichersberg” and illustrations according to thoughts about required storage temperature [own illustration]*

ΔT_{HE} Temperature Difference – Heat Exchanger; $T_{BF\ Corn}$ Backflow Temperature Corn drying; $\Delta T_{woodchip}$ Temperature difference usable for woodchip drying between outside Temperature in January and Corn drying backflow Temperature in September

Figure 202 shall illustrate two important facts. First, as can be seen due to the reference Temperature, the stored Energy level of a certain temperature, does not have the same value throughout the year.

This has a couple of positive effects, first during discharging the storage and due to inefficiencies the storage Temperature will drop, but also the outside Temperature is dropping which counteracts the devaluation of the stored energy.

It also points out, that a complete discharged (in terms of corn drying) storage, levelled down to a Temperature level of 15 – 20 °C, might still have some benefit if used for assisting wood drying in winter.

Secondly it shows that the additional peak load demand of heating oil can be avoided in an elegant way, as during cold periods the stored energy is valued up automatically.

Required temperatures in absolute numbers

Please note that the power distribution is not direct proportional to the Temperature due to: $cp_{air}=f(T)$

The following illustrations give some idea for typical operation states of the thermal storage system.

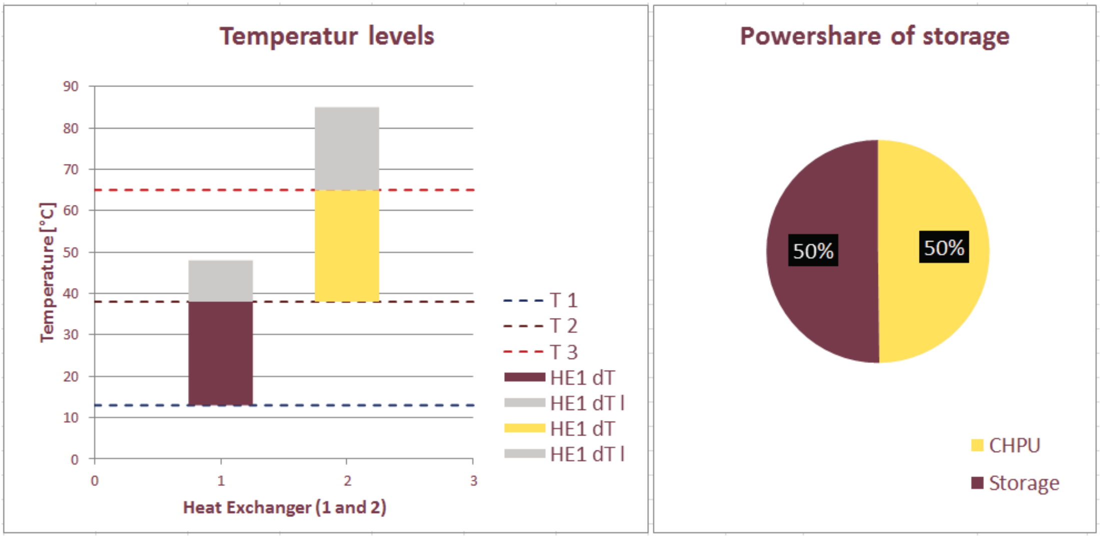


Figure 203 *Corn drying at average local temperature in September (= 13 °C), requires a storage Temperature of 49 °C for double capacity [own illustration*

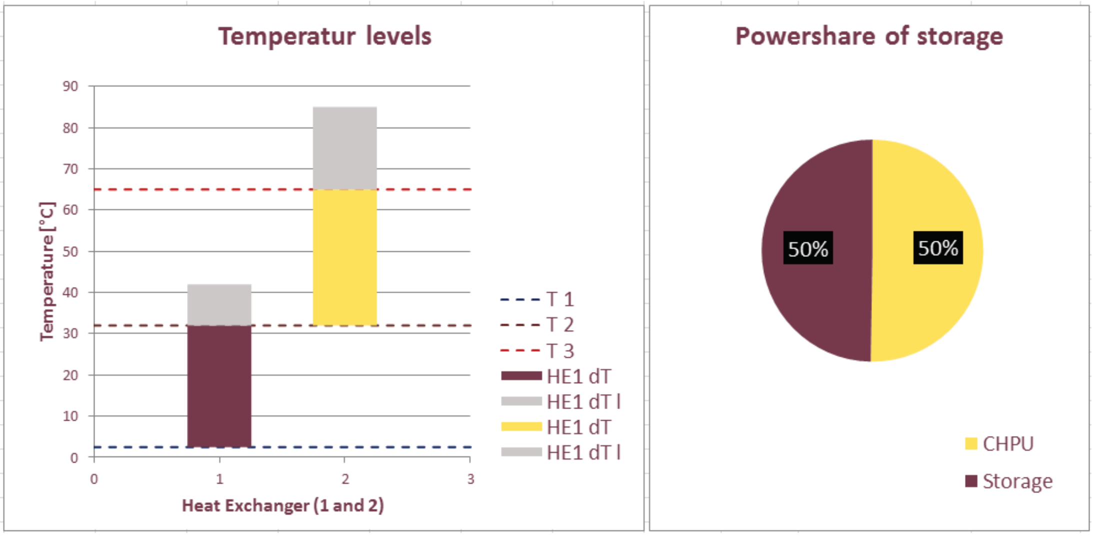


Figure 204 *Corn drying at average local temperature in November (= 2, 5 °C), requires a storage Temperature of 42 °C for double capacity [own illustration]*

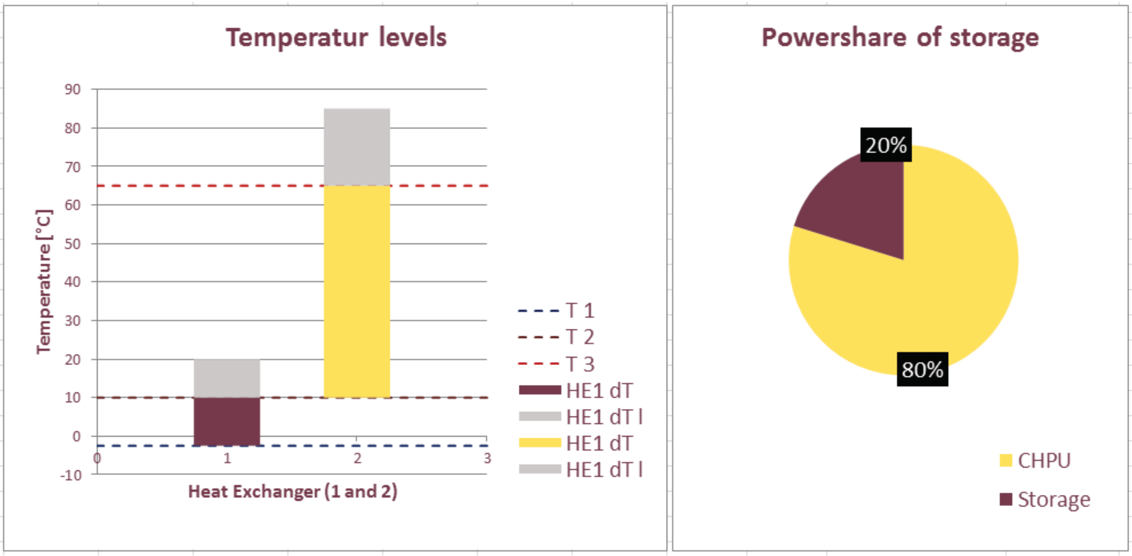


Figure 205 *Woodchips drying at average local temperature in December (=-1°C), resulting in an possible capacity increase of 20 % [own illustration]*

As illustrated the required storage is depending on the outside temperature, and therefore it plays a role when in the year the corn drying season takes place.

It should be noted that the storage Temperature could fall by 7 °C from September to November still yielding the same (relative) amount of capacity increase.

Very interesting is also, that even a discharged storage Temperature of just 20°C is still able to increase the wood chips drying power by 20 %. The additional amount of woodchips of course plays a minor role in economics, but the used energy could help to achieve the required amount of "reasonable used" energy even with a smaller storage.

20.7 Technical feasibility – Geology / Storage

20.7.1 Geological overview

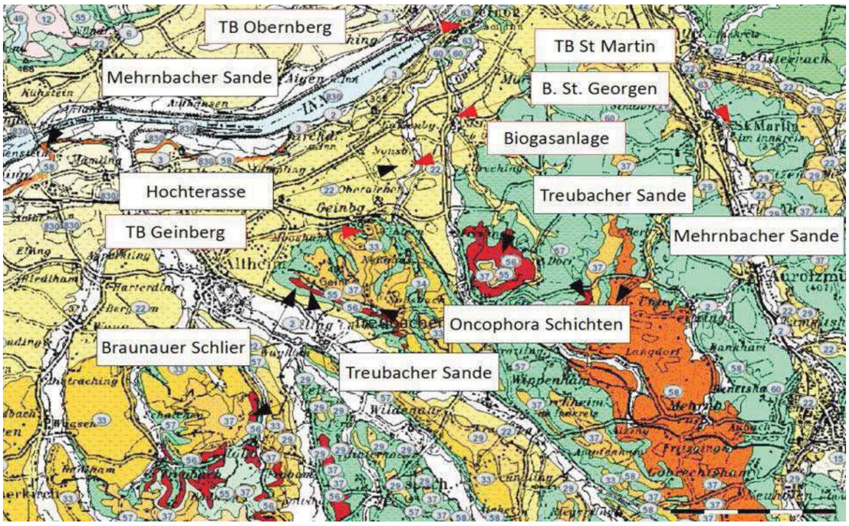


Figure 206 *Geological map of the area [modified 30]*

(Not translated, as mostly Names) Bigasanlage = biogas facility; TB Geinberg = Thermal well Geinberg; others Geological names of remarkable sequences, that will be described.

Geologically seen the biogas facility is situated in the Molasse basin or more exact in the “Braunauer Trog”, there on high terrace sediments. The surface near geology is described in Figure 207, which illustrates information given by local well diggers and Mr Schwarzmayr (Senior).

20.7.2 Shallow geology

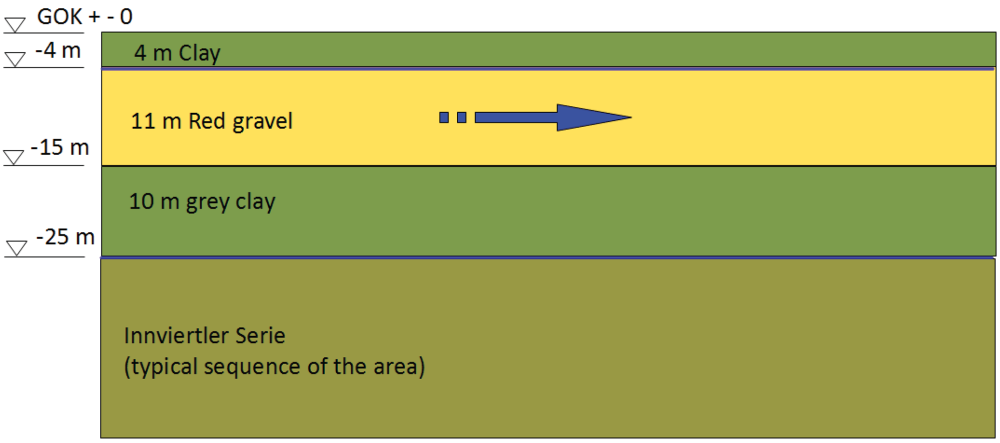


Figure 207 *Surface near geology as described by local well diggers and confirmed by Mr Schwarzmayr [own illustration]*

Δ 4m from -1 bis -5 m
Clay compact

Δ 4m von -5 bis -9 m
Middle – Finegravel, sandy, unconsolidated

Δ 2m von -9 bis -11 m
Clay, kiesig, gritty compact

Δ mind. 19 m von -11 bis -30 m
Clay, sandy, gritty average consolidated

Figure 208 *Sediment cores from the test well in St. Georgen bei Obernberg am Inn (~1km distance). [Own photography]*

The sequence is very typical for the Molasse basin Quaternary, the uppermost sequence is usually a tight clay structure with low percolation speeds. The first groundwater stage is within an unconsolidated gravel or coarse sand. In which usually very high groundwater speed occur; that can reach several km per year - especially near rivers.

At the bottom of the first ground water stage there is usually, but not always distinctly formed, a second tight clay layer, as last sequence of the Quaternary

Figure 209 *Assumed equipotential pressure lines in gravel section (Constructed according to surface height differences) [modified 30]*

Figure 209 *Assumed equipotential pressure lines in gravel section* shows assumed equipotential pressure lines around the biogas facility, as illustrated the groundwater table is slanted between (3 and 13 %). Assuming a permeability of 10^-3 and a porosity of 15 per cent, a filter velocity of approximately 2 m/d can be expected.

A direct usage of this aquifer is therefore not possible, the strong groundwater movement also hinders the usage of BTES (even if the sediments beneath the gravel section would be suitable) as the wells would need to be heat isolated in this (rather deep) section, and a usage of the ground could just be done beneath. Both, additional heat insulation and greater depth would increase investment costs considerable. Also increased drilling costs per meter are coming along with the unconsolidated gravel section. It shall be mentioned that the water chemistry in this sequence is usually uncomplicated.

20.7.3 Intermediate geology

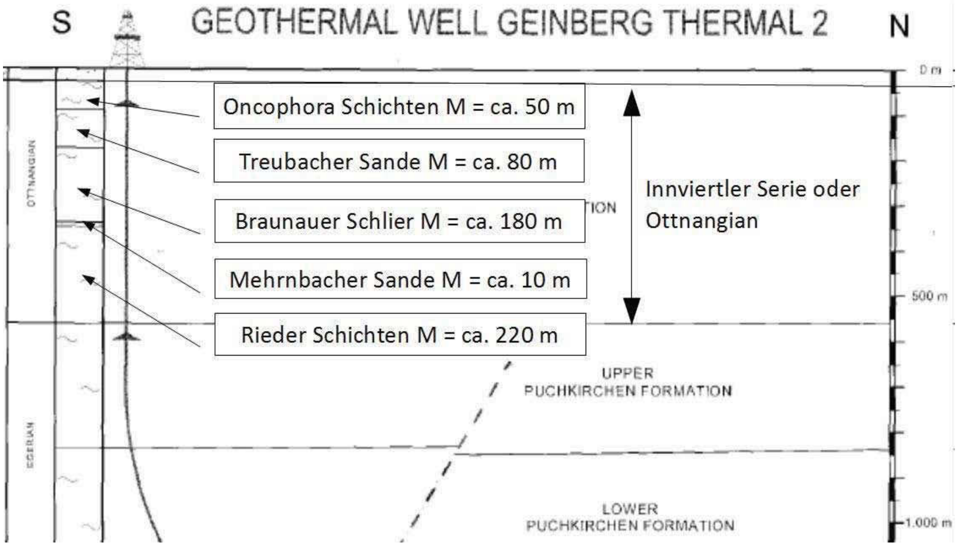


Figure 210 *Intermediate Geology, discussed according the 2, 5 km distanced geothermal well “Geinberg 2”. [Modified 31]*

Mostly names – therefore not translated. “Innviertler Serie” also known as “Glaokonitische Serie “(Please note that only the picture is taken from the source – however the geological interpretation is not. It was done by the author based on the geological maps and might be wrong. Especially the “Rieder Schichten” – Sequence might be mistaken, as it normally has a thickness of 60 – 80 m.)

“Oncophora Schichten”

The “Oncophora” - formation consists of silt - clay and mm thick sequences of wavy deposited silt and fine sands. The mineral composition is Quartz, Silica and some Carbon. [32]

“Treubacher Sande”

The “Treubacher Sande” - formation consists of moderately sorted fine sand and silt (Quartz). Often blocky or interrupted by very thin sequences of silt and clay between the sands. On the low side near to the “Braunauer Schlier” silt and clay content usually increases, forming smaller lens shaped blocks [32]

This formation can be found (on surface) to the south of the “Geinberg”, to the south west of the “Eichberg” (see also Figure 206), and a corresponding sequence was found in Bad Füssing (G) to the North West.

“Braunauer Schlier”

The “Braunauer Schlier”- formation consists of clay and silt with little amount of blocky, lens shaped or tilted layer fine sand deposits of minor thickness. [32]

“Mehrnbacher Sande”

The “Mehrnbacher Sande” – formation is very similar to the “Treubacher Sande” - formation, even though the clay and silt layers are deposited more tilted. [32]

“Rieder Schichten”

The “Rieder Schichten” – formation is consisting of clay and silts with frequent lens shaped fine sand. [32]

Hydro geology of sand sequences

General

Within the “Innvietler Serie” – sequence two types of underground water are reported. On the one hand pore water which is stored in the sand sequences, on the other hand water within fractures. [32] High permeable fractures could have fatal consequences for thermal aquifer storage projects.

As the sand layers are covered by compact clay sequences, artesian waters are common within the region; generally wells that produce ground water from these sands have a relatively low productivity. [32]

Groundwater movement

Within the “Innviertler Serie” - sequence no information about groundwater movements could be gained. Goldbrunner et. al. expects a pressure drop to the river “Inn”. [32] If no high permeable fractures are encountered especially in deeper layers relatively low groundwater movements can be expected. (Just own estimation)

Chemical composition

Especially mentioned shall be, that the underground water in these sequences is chemically seen not uncomplicated, and has caused precipitation problems in the past, even in drink water wells. Temperature and pressure changes could increase these problems.

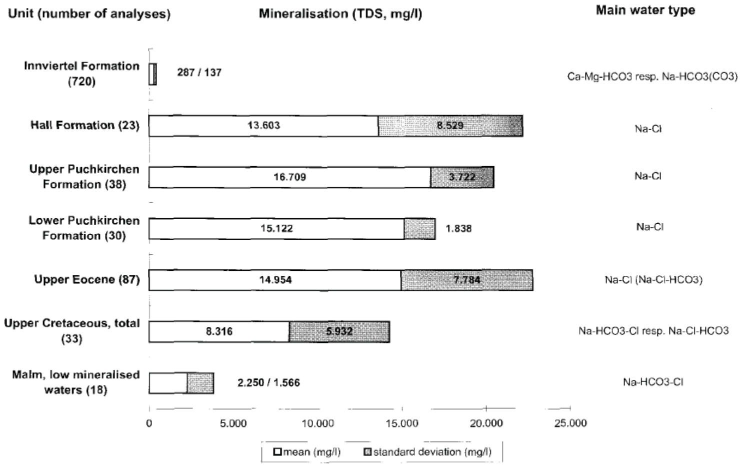


Figure 211 *Mineralisation of underground water in the Molasse basin [31]*

Productivity of water wells

The test well "Mehrnbach III" resulted in an average permeability value of 7, 2*10^-5 for the "Mehrnbacher Sande". This would yield a productivity of about 0,035 l/s per m formation. (Under steady state conditions assuming viscosity of 20°C water, for standard dimensioned water well) [32]

This is backed up by a study about artesian wells within the region, according to it this wells yield an average steady state production of 0, 07 l/s (Please note that this is achieved without additional pumping power). However this value is averaged over all sand sequences within the "Innviertler Serie" -Sequence. [32]

In a study about the "Atzbacher Sande" - formation (stratigraphic very similar to the "Treubacher Sande" – formation of GROISS this sands are said to have an average permeability 10^-5 – 10^-6 m/s [32]

However as known from water rights of the region, it is also possible to produce high rates out of these sequences. The wells "Mehrnbach I" and "Mehrnbach II" produce 13 l/s together. The well "St. Thomas" about 17 l/s. The three wells of the "Molkereigenossenschaft Ried (Neuhofen im Innkreis)" produce 14 l/s artesian water of sand sequences within the "Rieder Schichten" – formation (Net thickness 11 m)

This production rates cannot be explained with average permeability's and it can be assumed that there are high permeable fractures.

20.7.4 Deeper geology

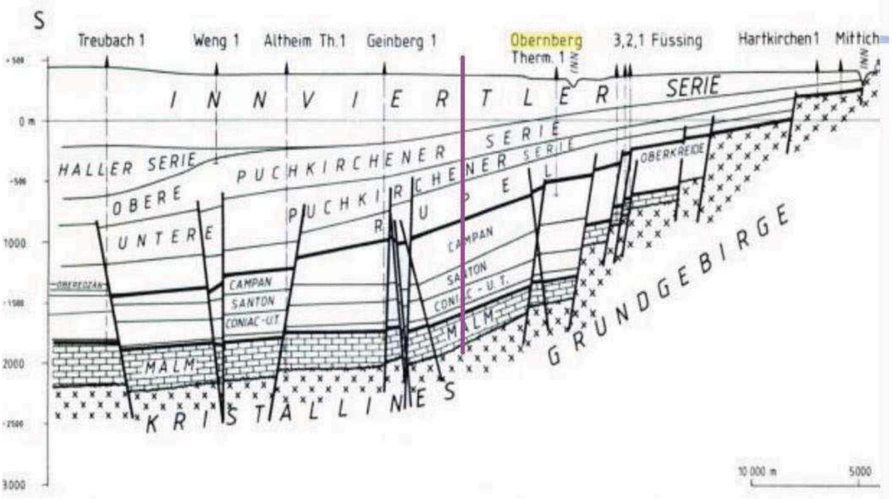


Figure 212 *Geological cross section - passing by the facility [unknown source]*

The deeper Geology is rather good known due to oil, gas and thermal wells in the region. Due to economic reasons the only possibly interesting sequence beside the “Innviertler Serie” Sequence is the “Obere Puchkirchner Serie” Sequence, which is well known for its sand and gravel deposits which are important gas fields in Upper Austria. However to the North with increasing distance to the Alps the sand and gravel deposits become less and less. In the description of drilling the thermal well Geinberg I these sections are mentioned as “pelitic in composition” which basically means corn sizes of smaller than 0,02 mm, which is clay and silt. However this sequence was not of interest in this report neither during drilling the well. It might possibly be that there are suitable fine sand sequences nevertheless.

20.8 Technical feasibility - Storage

20.8.1 Aquifer storage “Treubacher Sande” sequence

Due to the geological description an aquifer storage system in the “Treubacher Sande” formation might be possible. However it is not yet confirmed that they are in place at all neither being undisturbed by fractures.

If an approximate usable Temperature difference of 30 °C (50 - 40 °C max forward flow and 20 - 10 ° C backward flow) is assumed an approximate productivity of 2,5 – 3 l/s would be required using average permeability rates of 7*10^-5, a net thickness of 70 – 85 m of sand would be required. (Neglecting the positive influence of reduced viscosity at higher Temperatures). The “Treubacher Sande” seems to have a thickness of about 80 m in the “Geinberg I” well. However this assumption would be too optimistic as these sands are normally thinner and generally thin out to the north and west of Geinberg.

Still there is justified hope to find the "Treubacher Sande" formation at the location, to achieve the required net thickness however 3 or 4 production and the same amount (?) of injection wells are necessary.

It should be done research on the water chemistry and possible influences if pressure and Temperature are changed.

Storage size

As in a first approach it can be assumed that the storage size is governed by well spacing, it can be assumed, that the storage system can take the complete waste energy of the facility (600 – 800 MWh) it should be possible to regain the required energy during corn drying season (300 – 400 MWh). Therefore it should be able to fulfil the described targets (20.4), maybe beside target four – providing buffer storage – it might happen that the thermal storage system is not able to provide this, due to too fast cool out of small amount of energy.

Associated economic value

1.)	"KWK" Bonus	~ 60.000 €/y
2.)	Additional corn drying capacity	~ 27.000 – 36.000 €/y
3.)	Avoid the usage of peak load oil	~ 9000 € (average) €/y
Total		**~ 100.000 €/y**

Rough investment cost estimation

8 Production and Injection wells (a 100 m)	120.000 €
Personal costs	18.000 €
150 m of heat insulated pipes	50.000 €
Control and automation	25.000 €
Heat Exchanger	15.000 €
4 production pumps	5.000 €
1 Injection pump	4.000€
Other	25.000 €
Total	262000 €
Federal support (35 %)	92.000 €
Total	**170.000 €**

20.8.2 Hybrid storage “Gravel” layer

Beside the possibility of trying to store the thermal energy with in the “Treubach Sande” – formation, it could be tried to construct a thermal storage system within the gravel layer.

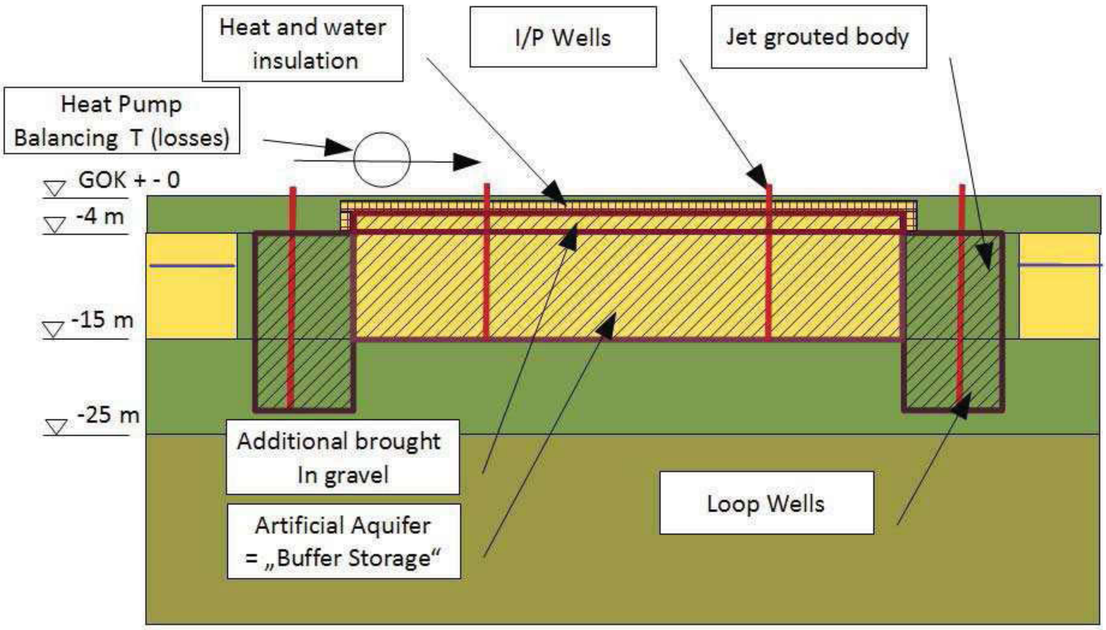


Figure 213 *Sketch of a hybrid storage system constructed in the gravel layer [own illustration]*

The basic idea is to create an artificial insulated aquifer, with the help of the jet grouting technique. This technique is commonly used for ground stabilisation or water insulation on construction sites. Usually the bodies have diameters from 0, 8 to 1, 2 m; however there are possibilities to create diameters up to 4, 0 m and more. This technique works especially well in no cohesive sand or finer gravel. It is generally known for being a relative cheap and reliable technique.

The aquifer would serve as the main storage at a higher Temperature level (70 – 85 °C). To the surface it would be heat and water insulated by foam glass gravel. Energy losses to the side and to some extent also to the depth would heat up the jet grouted bodies and could be regained by loop wells. For example by circulating cold backflow during night times to preheat before reinjection, or feed a heat pump to recharge the storage by levelling up the lost energy.

Figure 214 *Picture of a jet grouted body [33]*

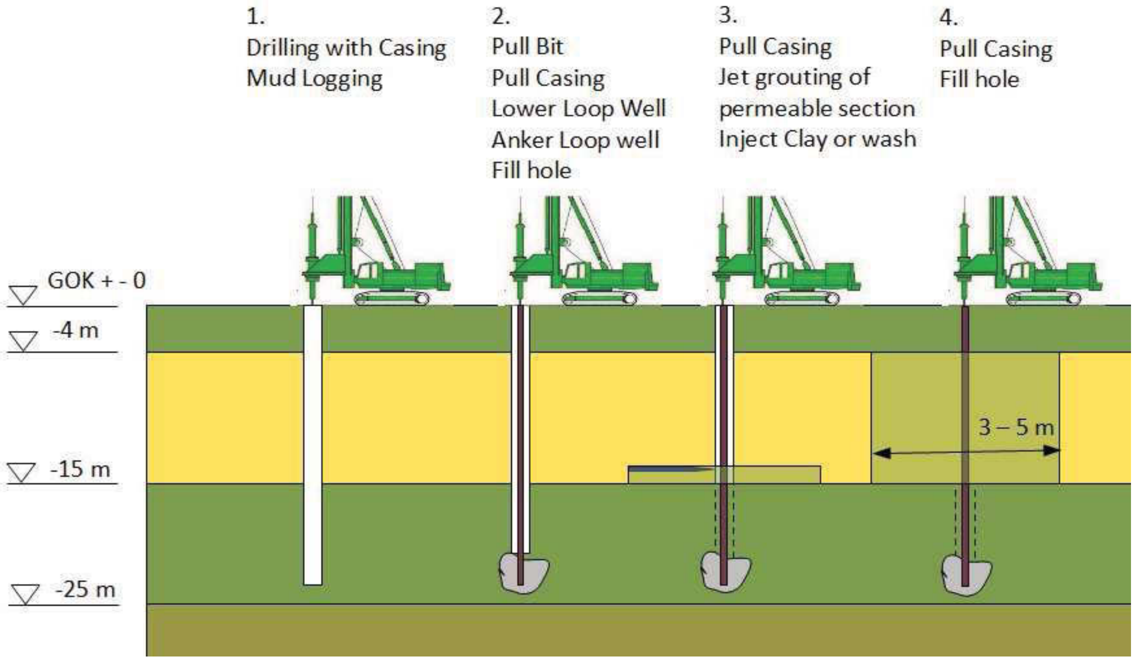


Figure 215 *Sketch of constructing a jet grouted body with an internal loop well in one step*

Anticipated construction process

1.) Remove humus
2.) Remove upper clay layer
3.) Prepare gained clay for reinjection – Cleaning + additives
4.) Construct jet grouted bodies and loop wells
5.) Drill Injection / Production wells
6.) Test sealing ability
7.) Bring in high porous gravel in former clay layer
8.) Water insulate gravel
9.) Bring in heat insulation (foam glass gravel)
10.) Restore surface

Storage size

In opposition to the aquifer storage system in this case additional storage volume creates additional investment. Therefore it is economically sense full to design the storage system in order to achieve the “KWK Bonus” (or in other words, not for maximum total profit, but for maximum profit per storage Volume)

It can be assumed that this type of storage would be suited to provide buffer space, according to Mr Schwarzmayr it can be approximated that an additional amount of 50 MWh heat energy can be utilized during the woodchip drying season because of this. Additionally as discussed in (20.6.1) the remaining energy after the corn drying season can be utilized for wood drying in winter.

If an energy level of 80 °C can be stored within the aquifer this would allow a usable Temperature difference of 55°C down to 25°C. The remaining heat energy at a level of 25°C still can be utilized down to approximate 10°C for wood drying.

Further it shall be assumed, that the jet grouted bodies are charged at a level of 60°C also. (The energy would there be charged last and drained first to minimize losses)

Associated economic value

1.) “KWK” Bonus	~ 60.000 €/y
2.) Additional corn drying capacity	~ 22.000 €/y
3.) Avoid the usage of peak load oil	~ 9000 € (average) €/y
Total	**~ 90.000 €/y**

Storage geometry

According to the needs in storage size and estimated heat capacities following geometry could be chosen. A ring concerning of columns of 3,5 m diameter and 3 m distance arranged in a ring of approximate 14 m radius. As illustrated in Figure 213 *Sketch of a hybrid storage system constructed in the gravel layer [own illustration]*. Please note that is very rough estimated, but there is no reliable data, about porosity and heat capacity of the sediments, so there cannot be exact calculations, but the order of magnitude will be correct.

Rough investment cost estimation

29 Jet grouted columns (d= 3, 5 m D= 9m)	340.000 €
29 Loop wells (D = 17 m)	30.000 €
Personal costs	18.000 €
Earth movement	10.000 €
Additional Gravel	15.000 €
Insulation	10.000 €
Surface Installations	50.000 €
Injection / Production Wells	5.000 €
Pumps	2.000 €
Other/Reserves	50.000 €
Federal support (35%)	- 185.500 €
Total	**344.500 €**

Comment to cost estimation “Jet grouted body”

The investment costs originate from a personal information by personal of the “Alpine Mayreder” for constructing a static stable and water tight building pit stabilization of that size in this Geology – however with columns of 1 m in diameter. The price includes Construction Costs Taxes and profit margin. However it can be expected, that the construction price can be reduced, as columns of larger diameter are more cost efficient and there is no need for static stabilization. [34]

Advantages of the hybrid storage system

Even though this system is in need of higher investments it has some advantages over an aquifer storage system

1.) Much less demanding on fitting Geology, inbounded shallow gravel layers in the shallow geology are very common in our region.
2.) Storage can be embedded in an Energy system, offering the possibility of on the one hand charging and recharging heat energy, but also electric energy can be used in times of low demand to regain losses or level up storage energy via a heat pump.
3.) Higher Temperatures achievable
4.) Better Efficiency

20.9 Conclusion thermal storage project “Schwarzmayr”

The existing facility offers in principle good circumstances for a thermal storage pilot project. The corn drying facility provides an ideal costumer for low Temperature Energy, which is favourable for these kinds of projects. Additionally remaining energy can be utilized for wood drying at an even lower level later in the year. Beneficial is also the relatively short storage duration.

Economically seen the thermal storage can create high total revenues as well as high revenues per stored MWh.

The Geology offers some interesting options but also risks, ways of cost efficient exploration and measurement would be in need.

Over all in this case the aquifer storage system within the shallow sand regions would be probably the bestchoice, if the anticipated geological structure turns out to have required properties. However the Hybrid storage system has most likely the higher potential, due to its described beneficial properties.

20.10 Future visions – Embedded intelligent thermal storage system

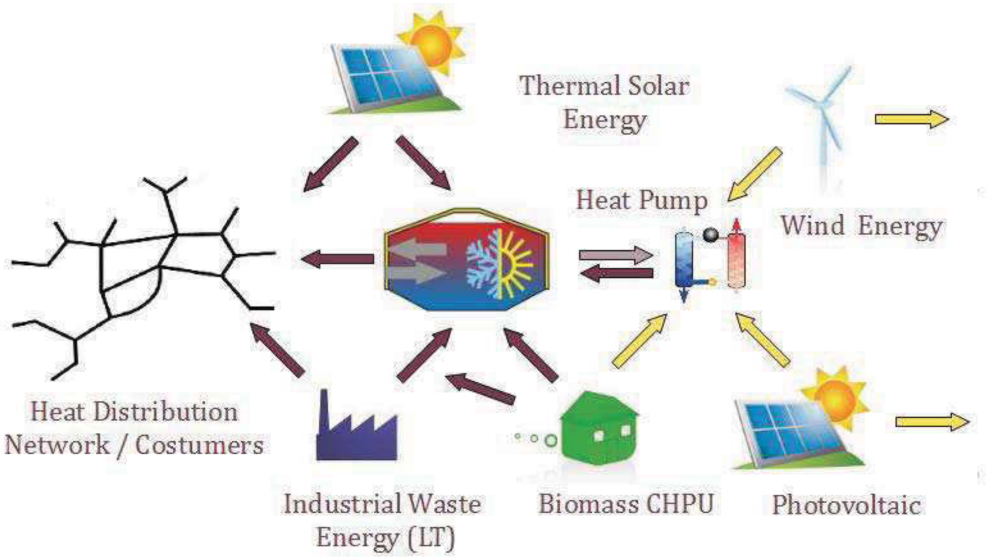


Figure 216 Embedded intelligent thermal storage system [own illustration]

Basic idea is to combine a thermal storage unit with a heat pump to allow not only increasing of heat energy value, but also increasing electric energy value in times of little demand / overproduction.

The described storage type “Hybrid Storage” would perfectly fit for this purpose at it anticipates to regain energy losses via a heat pump, and the system offers inertia allowing being flexible in time.

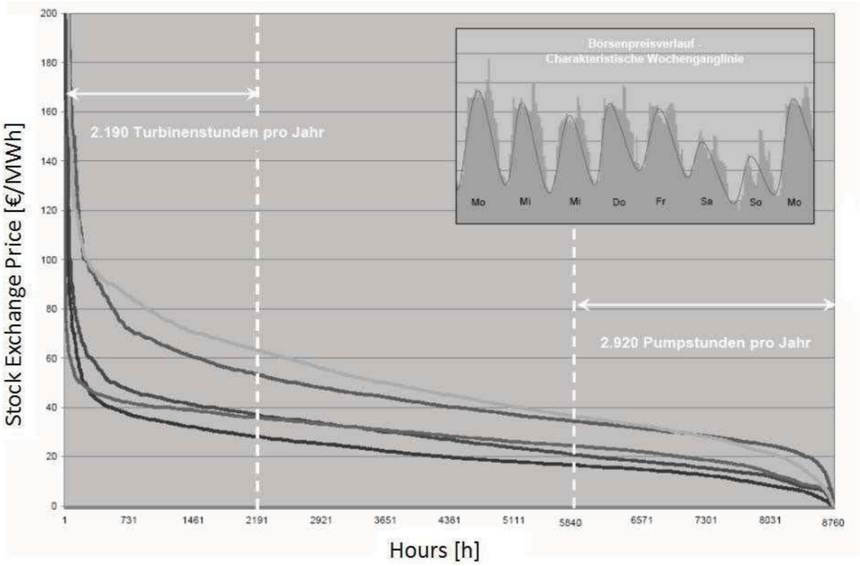


Figure 217 Electricity stock exchange prices – Year 2002 – 2006; the lines referring to different years, 2006 reflected by the lightest to 2002 reflected by darkest line

Low demand electricity - Creation of value

Sell to electricity provider:	~ 35	€/MWh
Regain heat energy (COP: 3, 5)	~ 150	€/MWh

Due to the actual legislation such systems are however not interesting, because the electricity net provider is forced to take electricity produced by renewables (except large water plants) any time at a predefined price.

Nevertheless this system would match some of Austrian and Germany’s development targets for the next 10 years, such as:

- Developing of cheap thermal storages
- Increase amount AND grid compatibility of renewable electric energy
- Integrating heat pumps in energy systems
- Achieve energy autarchy in demonstration regions
- Increasing efficiency of biogas facilities by utilizing waste heat energy to a greater proportion
- Usage of industrial waste energy

21 Final conclusion from the drilling engineer's point of view

It seems as if the storage of fluids in relatively shallow depth could play a major role if Petroleum Engineering Technology shall be applied in the Renewable Energy Sector.

No matter if thermal storage (app. 0 +), compressed air storage (250 m +) or CO_2 storage (800 m +). Cost efficient Drilling technology will be in need, for exploration purposes as well as for production/injection wells.

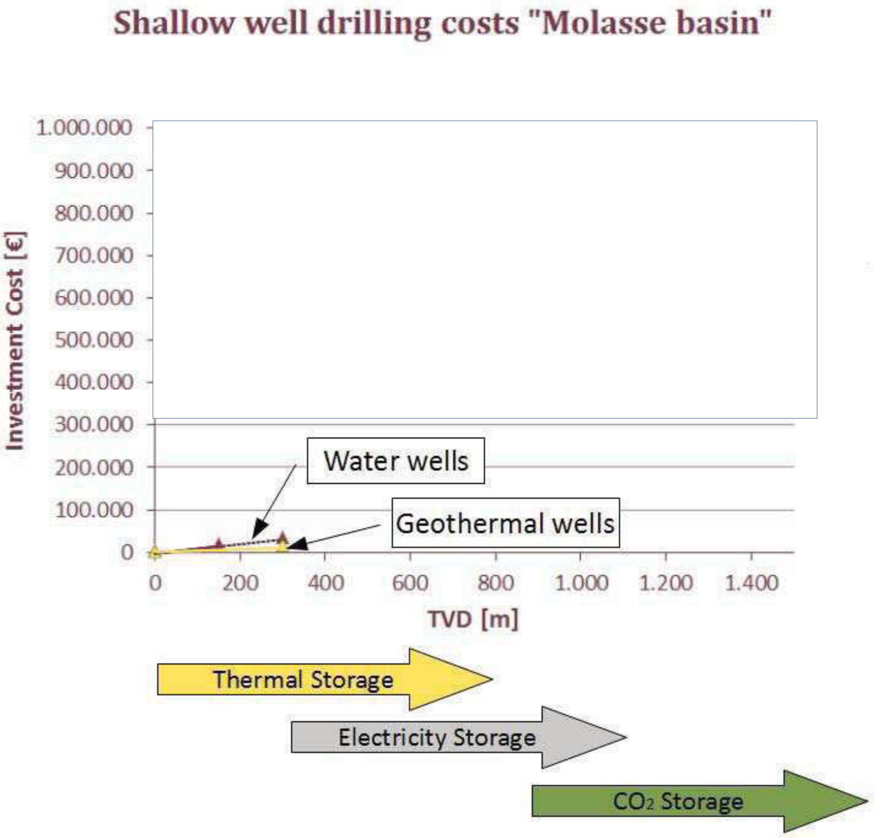


Figure 218 *Shallow well drilling costs "Molasse Basin" [own illustration]*

Illustrated are the drilling investment cost [€] vs. TVD [m], for the three shallowest oil and gas wells drilled by RAG since 2000 (Rosenau, Gilgenberg, Wegscheid 3), and approximated cost functions for water and geothermal wells.

(Rag data cleared in public version)

Figure 218 clearly illustrates what can be expected to be the challenges for Drilling Engineering concerning constructing storage facilities.

Even though RAG is doing a very good job in reducing their drilling costs, the rigs are constructed for drilling as deep as 5000 m, being able to reach most potential oil, gas or geothermal prospects.

However the shallow region would require special rigs and drilling technology to reduce costs. Maybe some techniques can also be adapted from well diggers. Constructing large numbers of shallow wells might be a topic in future. Due to the relative low depth and the requirement of multiple wells at one place, and numerous prospects over all, it can be expected, that there is room to climb down the learn curve, adapting "new" drilling technology, bringing the drilling process from a single unit production per prospect to a mass product, with all the room for optimization coming along with that.

22 Bibliography

[1] **Energie-Control GmbH**. *Ökostrombericht gemäß § 25 Abs 1 Ökostromgesetz, 2009*

[2] **C.A.R.M.E.N e.V**. *http://www.carmen-ev.de/*

[3] **Österreichisches Lebensmittelministerium** *Kommunikationsratgeber zur Projektierung von Biogasanlagen*

[4] **UMSICHT Frauenhofer** *Leitfaden Nahwärme (Hauptteil und Anhang)*

[5] **WINTER Institut für Grundlagen der Verfahrenstechnik und Anlagentechnik Universität Graz (et.al)** *Untersuchung der Gleichzeitigkeit in kleineren und mittleren Wärmenetzen*

[6] **C.A.R.M.E.N e.V** *RDesign Handbuch*

[7] **Michael Dewein** *Machbarkeitstudie zur Geothermie Fernwärmeversorgung*

[8] **Bayerisches Staatsministerium für Wirtschaft, Infrastruktur, Verkehr und Technologie** *Bayrischer Geothermie Atlas*

[9] **ITAG** Geothermie Workshop (Done for RAG Engineers)

[10] **U.S. Department of Energy** *Energy Efficiency & Renewable Energy Chapter 6 Drilling Technology and Costs*

[11] **Ernst Doering** *Grundlagen der Thermodynamik*

[12] **(ISBN 3-7785-7796-4) 2006 C.F. Müller Verlag,** Heidelberg *Erdwärmenutzung*

[13] **Dr. Silke Köhler** *Geothermisch angetriebene Dampfkraftprozesse – Analyse und Prozessvergleich binärer Kraftwerke*

[14] **Volker Sperlich** *Übungsaufgaben zur Thermodynamik mit Mathcad*

[15] **ASUE** *BHKW – Kenndaten*

[16] **Olof Anderson SWECO VIAK** *Aquifer Thermal Energy Storage (ATES)*

[17] **T. Schmidt et. al.** *Die solar unterstützte Nahwärmeversorgung im saisonalen Aquifer – Wärmespeicher in Rostock – Ergebnisse nach vier Betriebsjahren*

[18] **Hans-Peter Ebert et.al.** *Optimierung von Erdwärmesonden*

[19] **Österreichische Energieagentur** *www.energyagency.at*

[20] **SOLITES** *Solare Nahwärme und Langzeit-Wärmespeicher*

[21] **Reuß et. al. Bayerisches Zentrum für Angewandte Energieforschung** *„Solare Nahwärme Attenkirchen - Erfahrungen beim Bau und im Betrieb“*

[22] **BMBF Verbundprojekt** *Technologien und Kosten der Biogasaufbereitung und Einspeisung in das Erdgasnetz. Ergebnisse der Markterhebung 2007 - 2008*

[23] **C.A.R.M.E.N** *Biogas Messprogramm II 61 Biogasanlagen im Vergleich*

[24] **ALSTOM** C*AES*

[25] **Hansjörg Gober, Karl Nackler** *Neue Überlegungen zur Speichergrößenoptimierung bei Pumpspeicherkraftwerken*

[26] **Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit** *Umweltpolitische Innovations- und Wachstumsmärkte aus Sicht der Unternehmen*

[27] **Johannes Schwarzmayr** *personal information*

[28] **Markus Böckelmann** *Untersuchungen zur Konservierung von Körnermais mitmikrowellenunterstützter Warmlufttrocknung*

[29] **Krischer & Kast** *Trocknungsverlauf eines kapillarporösen Gutes mit hygroskopischem Bereich*

[30] **Österreichisches Vermessungsamt** *D.O.R.I.S*

[31] **Goldbrunner** *Hydrogeology of Deep Groundwater in Austria*

[32] **Christian Rupp, Geologische Bundesanstalt, et al.** *Geologische Karte Österreichs - Erläuterung zu Blatt 47 Ried im Innkreis*

[33] **RATIO** *„RAS Jet grouted body“*

[34] **Alpine Mayreder- Schweiger Hans Peter** *Personal Information*

[35] **ARGE Kompost und Biogas**

[36] **Frauenhofer Institut „***Beseitigung technischer, rechtlicher und ökonomischer Hemmnisse bei der Einspeisung biogener Gase in das Erdgasnetz zur Reduzierung klimarelevanter Emissionen durch Aufbau und Anwendung einer georeferenzierten Datenbank“*